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**KEPUTUSAN**
**REKTOR UNIVERSITAS SRIWIJAYA**
**Nomor: 0139/UN9/KP/2016**

**Tentang**

**PERSETUJUAN JUDUL DAN PENUNJUKAN TENAGA PELAKSANA**
***PENELITIAN KOLABORASI INTERNASIONAL***
**UNIVERSITAS SRIWIJAYA TAHUN ANGGARAN 2016**

**REKTOR UNIVERSITAS SRIWIJAYA**

Menimbang :

a. Bahwa untuk melaksanakan kegiatan penelitian yang bersumber dari dana DIPA Universitas Sriwijaya tahun 2016 perlu persetujuan judul penelitian dan penunjukan tenaga pelaksana penelitian;

b. Bahwa mereka yang namanya tertera dalam kolom (2) lampiran surat Keputusan ini dianggap mampu dan memenuhi syarat untuk ditunjuk sebagai tenaga peneliti dengan judul pada kolom (3), serta alokasi biaya tercantum pada kolom (5) Surat keputuan ini;

c. Bahwa sehubungan dengan huruf b di atas perlu diterbitkan Surat Keputusan sebagai pedoman dan landasan hukumnya.

Mengingat :

1. Undang-undang No.20 tahun 2003, tentang Sistem Pendidikan NasionaL;
2. Undang-undang No.12 tahun 2012, tentang Pendidikan Tinggi;
3. Peraturan Pemerintah No. 66 tahun 2010, tentang Pengelolaan dan Penyelengaraan Pendidikan;
4. Keputusan Mendikbud R.I. No. 64/0/2003, tentang Statuta Unsri;
5. Keputusan Menteri Riset, Teknologi dan Pendidikan Tinggi R.I. Nomor: 334/M/KP/XI/2015, tentang Pemberhentian dan Pengangkatan Rektor Universitas Sriwijaya.
6. Keputusan Menteri Riset, Teknologi dan Pendidikan Tinggi R.I. No. 12 tahun 2015, tentang Organisasi dan Tata Kerja Unsri;

**MEMUTUSKAN**

Menetapkan : KEPUTUSAN REKTOR UNIVERSITAS SRIWIJAYA TENTANG PERSETUJUAN JUDUL DAN PENUNJUKAN TENAGA PELAKSANA PENELITIAN KOLABORASI INTERNASIONAL UNIVERSITAS SRIWIJAYA TAHUN ANGGARAN 2016

KESATU : Menyetujui judul penelitian yang tercantum pada kolom (3) dan menunjuk peneliti yang namanya tercantum pada kolom (2) serta alokasi biaya yang tercantum pada kolom (5) surat keputusan ini;

KEDUA : Jumlah biaya yang disetujui sebagaimana tercantum pada kolom (5) lampiran surat keputusan ini dibebankan kepada anggaran DIPA Universitas Sriwijaya tahun anggaran 2016;

KETIGA : Memberi wewenang kepada Ketua Lembaga Penelitian dan Wakil Rektor II Universitas Sriwijaya untuk menandatangani Surat Perjanjian Pelaksana Penelitian;

| | | |
|---|---|---|
| KEEMPAT | : | Memberi wewenang kepada Ketua Lembaga Penelitian Universitas Sriwijaya untuk melaksanakan monitoring dan evaluasi terhadap pelaksanaan penelitian serta menyetujui laporan hasil penelitian; |
| KELIMA | : | Keputusan ini berlaku sejak tanggal ditetapkan, dengan ketentuan bahwa segala sesuatu akan diubah dan/atau diperbaiki sebagaimana mestinya apabila ternyata terdapat kekeliruan dalam keputusan ini. |

DITETAPKAN DI INDERALAYA
PADA TANGGAL 26 APRIL 2016

REKTOR,

ANIS SAGGAFF
NIP. 19621028 198903 1 002

Tembusan:
1. Kementerian Riset, Teknologi dan Pendidikan Tinggi R.I.
2. Direktur Riset dan Pengabdian kepada Masyarakat Kemenristekdikti R.I.
3. Wakil Rektor I, II, III dan IV Universitas Sriwijaya
4. Dekan Fakultas di lingkungan Universitas Sriwijaya
5. Ketua Lembaga di lingkungan Universitas Sriwijaya
6. Kepala Biro di lingkungan Universitas Sriwijaya
7. Kepala Bagian Keuangan BUK Universitas Sriwijaya
8. Yang bersangkutan

KEMENTERIAN RISET, TEKNOLOGI DAN PENDIDIKAN TINGGI
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**SURAT PERJANJIAN PENUGASAN PELAKSANAAN KEGIATAN PEKERJAAN PENELITIAN KOLABORASI INTERNASIONAL UNIVERSITAS SRIWIJAYA**
Nomor : 605/UN9.3.1/LT/2015

Pada hari ini, senin tanggal dua puluh lima bulan april tahun dua ribu enam belas, kami yang bertandatangan dibawah ini :

| | | | |
|---|---|---|---|
| 1. | **Prof. Dr. Ir. H. Muhammad Said, M.Sc** | : | Sebagai Ketua Lembaga Penelitian Universitas Sriwijaya yang berkedudukan di Inderalaya, dalam hal ini bertindak untuk dan atas nama Rektor Universitas Sriwijaya, untuk selanjutnya disebut PIHAK PERTAMA |
| 2. | **Dipl.-Ing.Ir.Amrifan Saladin Mohruni,Ph.D** | : | Sebagai Ketua Peneliti Penelitian Kolaborasi Internasional tahun 2015 dari Fakultas Teknik Universitas Sriwijaya yang berkedudukan di Indralaya, dalam hal ini bertindak untuk dan atas nama Tim Peneliti tersebut selanjutnya disebut PIHAK KEDUA |

Kedua belah pihak berdasarkan kepada :
1. Undang-Undang Republik Indonesia No. 17 tahun 2003 Tentang Keuangan Negara;
2. Undang-Undang Republik Indonesia No. 20 tahun 2003 Tentang Sistem Pendidikan Nasional;
3. Undang-Undang Republik Indonesia No. 12 tahun 2012 Tentang Pendidikan Tinggi;
4. Undang-Undang Republik Indonesia No. 01 tahun 2004 Tentang Perbendaharaan Negara;
5. Undang-Undang Republik Indonesia No. 15 tahun 2004 Tentang Pemeriksaan dan Tanggung Jawab Keuangan Negara;
6. Peraturan Presiden No.13 Tahun 2015 tentang Kementerian Riset, Teknologi dan Pendidikan Tinggi
7. Peraturan Menteri Riset, Teknologi dan Pendidikan Tinggi No.12 Tahun 2015 tentang Organisasi dan Tata Kerja Universitas Sriwijaya
8. Surat Keputusan Rektor Universitas Sriwijaya No. 007/UN9/KP/2016 tentang Pengangkatan Pejabat Pengelola Keuangan-BLU dalam Lingkungan Universitas Sriwijaya;
9. Keputusan Rektor Universitas Sriwijaya No.0083/UN9/KP/2013 Tentang Perpanjangan Masa Tugas Ketua Lembaga Penelitian Universitas Sriwijaya;
10. Keputusan Rektor Universitas Sriwijaya No. 00139/UN9/KP/2016 tentang Persetujuan Judul dan Penunjukan Tenaga Pelaksana Penelitian Kolaborasi Internasional Universitas Sriwijaya Tahun Anggaran 2016;
11. Surat Perjanjian Penugasan Pelaksanaan Penelitian Kolaborasi Internasional Universitas Sriwijaya Tahun Anggaran 2015 Nomor 609/UN.3.1/LT/2016 tanggal 28 April 2016;
12. Daftar Isian Pelaksanaan Anggaran (DIPA) Universitas Sriwijaya Nomor 042.01.2.400953/2016 tanggal 07 Desember 2015.

PIHAK PERTAMA dan PIHAK KEDUA secara langsung bersama-sama telah bersepakat mengikat diri dalam suatu Perjanjian Pelaksanaan Penugasan Penelitian Kolaborasi Internasional Universitas Sriwijaya dengan ketentuan dan syarat-syarat diatur dalam pasal-pasal berikut :

**PASAL 1**
**Pelimpahan Wewenang**

PIHAK PERTAMA sebagai penerima wewenang dari Rektor Universitas Sriwijaya, memberikan tugas kepada PIHAK KEDUA dan PIHAK KEDUA menerima tugas tersebut sebagai penanggungjawab pelaksanaan penelitian yang berjudul **" Green Machining On Titanium Alloy To Foster Environmental Sustainability"**

**PASAL 2**
**Waktu Pelaksanaan**

**PIHAK KEDUA** harus melaksanakan Pekerjaan Penelitian Kolaborasi Internasional Universitas Sriwijaya, yang dimaksud pada Pasal 1 selambat-lambatnya dimulai dari tanggal 25 April 2016 akan selesai pada tanggal 07 Desember 2016;

**PASAL 3**
**Monitoring dan Evaluasi**

(1) Kegiatan Monitoring dan Evaluasi akan dilakukan oleh PIHAK PERTAMA terhadap PIHAK KEDUA pada bulan September 2016;

(2) Kedua Pihak, PIHAK PERTAMA dan PIHAK KEDUA menandatangani berita acara serah terima laporan kemajuan dan laporan penggunaan dana 70%.

(3) Pada kegiatan monitoring dan evaluasi PIHAK KEDUA menyiapkan dan menyerahkan kepada PIHAK PERTAMA kelengkapan berupa:
   a) Catatan harian kegiatan penelitian, berupa Buku Catatan Harian Penelitian (BCHP/log book) yang terjadwal/periodik yang ditulis tangan
   b) Laporan Kemajuan dua eksempelar yang dijilid seperti proposal
   c) Bukti Setor Pajak dan Bukti Pengeluaran (Kwitansi, Nota, SPDD dll).

**PASAL 4**
**Luaran Hasil Penelitian**

(1) PIHAK KEDUA berkewajiban menindaklanjuti dan mengupayakan hasil penelitian yang dilakukan untuk dipublikasikan dalam **Jurnal Internasional**, dan/atau dalam bentuk luaran lainnya, sebagaimana yang dijanjikan dalam usulan penelitian.

(2) PIHAK KEDUA wajib melaporkan secara tertulis dan menyerahkan perolehan yang tersebut pada ayat (1) kepada PIHAK PERTAMA.

(3) Perolehan sebagaimana dimaksud pada ayat (1) dimanfaatkan sebesar-besarnya pelaksanaan tridharma perguruan tinggi.

**PASAL 5**
**Mekanisme Pembayaran**

(1) PIHAK PERTAMA memberikan dana untuk kegiatan sebagaimana dimaksud pada pasal 1 sebesar **Rp. 180.000.000 (Seratus Delapan Puluh Juta rupiah)** tidak dipotong pajak yang dibebankan kepada Anggaran DIPA Nomor 042.04.2.400953/2016 tanggal 07 Desember 2015;.

(2) Pembayaran dana pelaksanaan penelitian sebagaimana dimaksud pada ayat (1) dibayarkan sesuai dengan mata anggaran yang tersedia dan dibayarkan secara bertahap dengan ketentuan sebagai berikut :
   a. Pembayaran tahap pertama sebesar 70% bernilai **Rp. 126.000.000- (Seratus Dua Puluh Enam Juta rupiah)** dipotong pajak PPh Pasal 23 sebesar 2%, dibayarkan setelah PIHAK KEDUA menyerahkan rincian penggunaan dana 70% dan tiga lembar materai enam ribu.

   b. Pembayaran tahap kedua sebesar 30% bernilai **Rp. 54.000.000,- (Lima Puluh Empat Juta rupiah)** dipotong pajak PPh Pasal 23 sebesar 2%, dibayarkan setelah PIHAK KEDUA menyerahkan Laporan Akhir Penelitian dan luaran hasil penelitian sesuai pasal 4 kepada PIHAK PERTAMA

## PASAL 6
## Pembayaran Pajak

PIHAK KEDUA Berkewajiban membayar pajak ke Kantor Pelayanan Pajak setempat yang berkenaan dengan kewajiban pajak berupa:

1. Pembelian barang dan jasa dikenai PPN sebesar 10% dan PPh pasal 22 sebesar 1,5%;
2. Belanja honorarium di kenai PPh pasal 21 dengan ketentuan:
   a. 5% Bagi yang memiliki NPWP untuk golongan III, serta 6% bagi yang tidak memiliki NPWP
   b. Untuk golongan IV sebesar 15% dan pajak-pajak lain serta mempertanggungjawabkan keuangan sesuai dengan ketentuan yang berlaku

## PASAL 7
## Penyerahan Hasil Pekerjaan

1. PIHAK KEDUA harus menyerahkan Laporan Akhir Pekerjaan Penelitian Kolaborasi Internasional sebanyak 4 (empat ) eksemplar dengan menyertakan Softcopy-nya.

2. Laporan Kemajuan dan Laporan Akhir Pekerjaan Penelitian Kolaborasi Internasional harus memenuhi ketentuan sebagai berikut :
   a. Ukuran kertas A4
   b. Warna Kulit (Cover) **Hijau Muda**
   c. Di bagian bawah dari kulit laporan ditulis;

Dibiayai dari Anggaran DIPA Universitas Sriwijaya<br>
Nomor 042.01.2.400953/2016 tanggal 7 Desember 2015<br>
Sesuai dengan Surat Perjanjian Penugasan Pelaksanaan Penelitian<br>
Kolaborasi Internasional Universitas Sriwijaya<br>
Nomor 605/UN9.3.1/LT/2016<br>
Tanggal 25 April 2016

## PASAL 8
## Perubahan Personalia

(1) Apabila PIHAK PERTAMA berhenti dari jabatannya, sebelum pelaksanaan perjanjian ini selesai, maka kewajiban menyelesaikan tanggungjawab dalam perjanjian ini dilimpahkan kepada pejabat baru yang menggantikannya.

(2) Apabila terjadi ada ketua peneliti sebagaimana dimaksud pada Pasal 1 tidak dapat menyelesaikan pelaksanaan penelitian ini, maka PIHAK KEDUA wajib menunjuk pengganti ketua pelaksana yang merupakan salah satu anggota tim dan dilaporkan secara tertulis kepada PIHAK PERTAMA yang akan diteruskan kepada Rektor Universitas Sriwijaya.

## PASAL 9
## Sanksi- sanksi

(1) Apabila batas waktu penelitian habis sesuai dengan jadwal yang telah ditetapkan Lembaga Penelitian Universitas Sriwijaya, sedangkan pelaksana penelitian belum menyerahkan hasil pekerjaan seluruhnya kepada PIHAK PERTAMA, maka PIHAK KEDUA dikenakan denda 1 ‰ (satu permil) dari setiap hari keterlambatan sampai dengan setinggi-tingginya 5% (lima persen) dari nilai dana penelitian yang tercantum dalam Pasal 5 ayat 1 Surat Perjanjian Penugasan Pelaksanaan Penelitian, terhitung sejak tanggal jatuh tempo yang telah ditetapkan pada Pasal 2 Surat Perjanjian ini sampai dengan berakhirnya pembayaran dana penelitian oleh Bendahara Pengeluaran Pembantu Lembaga Penelitian Universitas Sriwijaya.

(2) Apabila PIHAK KEDUA tidak dapat melaksanakan tugas sebagaimana yang dimaksud dalam Pasal 1, maka PIHAK KEDUA harus mengembalikan dana yang telah diterimanya ke Rektor Universitas Sriwijaya melalui Rekening Bendahara Pengeluaran BNI No. 0070572816 (untuk Pengembalian dalam Tahun Anggaran yang sama) atau Rekening Bendahara Penerimaan BNI No. 0070570115 (untuk Pengembalian Setelah tahun Anggaran berjalan).

(3) Apabila telah melampaui Tahun Anggaran Berjalan Peneliti tidak dapat memenuhi kewajibannya, maka selanjutnya PIHAK PERTAMA akan mempertimbangkan usulan Pekerjaan Penelitian Kolaborasi Internasional Universitas Sriwijaya yang bersangkutan pada periode berikutnya.

**PASAL 10**
**Peralatan Penelitian**

Hasil penugasan penelitian berupa peralatan dan/atau alat yang dibeli dari kegiatan penelitian ini adalah milik Negara yang dapat dihibahkan kepada Lembaga/Institusi lain melalui Surat Keterangan Hibah.

**PASAL 11**
**Penyelesaian Perselisihan**

Apabila terjadi perselisihan antara kedua pihak dalam pelaksanaan perjanjian ini, maka PIHAK PERTAMA akan melaporkan kepada Rektor Universitas Sriwijaya untuk ditetapkan tindakan selanjutnya. Apabila penyelesaiannya harus melalui ketentuan hukum, maka kedua belah pihak memilih domisili hukum di Pengadilan Negeri Palembang.

**PASAL 12**
**Biaya Materai**

Surat Perjanjian Penugasan Pelaksanaan Penelitian ini dibuat rangkap 3 (tiga), diantaranya bermaterai cukup sesuai dengan ketentuan yang berlaku, dan biaya materainya dibebankan kepada PIHAK KEDUA.

| PIHAK PERTAMA | PIHAK KEDUA |
|---|---|
| METERAI TEMPEL TGL. 20 E6E54ADF817406909 6000 ENAM RIBU RUPIAH | |
| Prof. Dr. Ir. H. Muhammad Said, M.Sc. | **Dr. Dipl.-Ing.Ir.Amrifan Saladin Mohruni,Ph.D** |
| NIP. 196108121987031003 | NIP. 196409111999031002 |

# FINAL REPORT INTERNATIONAL RESEARCH COLLABORATION

## GREEN MACHINING ON TITANIUM ALLOY TO FOSTER ENVIRONMENTAL SUSTAINABILITY

**Dipl.-Ing. Ir. Amrifan Saladin Mohruni, Ph.D**
**Ir. Erna Yuliwati, M.T., Ph.D**
**Prof Safian Sharif**
**Prof Ahmad Fauzi Ismail.**

**UNIVERSITAS SRIWIJAYA**
**UNIVERSITI TEKNOLOGI MALAYSIA**
**DECEMBER 2016**

**Halaman Pengesahan**

Research Title : GREEN MACHINING ON TITANIUM ALLOY TO FOSTER ENVIRONMENTAL SUSTAINABILITY

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Research Duration : 3 years

| Years | Proposed to DGHE | Counter Budget from Collaborator |
|---|---|---|
| Year 1 | IDR: 200.000.000 | |
| Year 2 | IDR: 200.000.000 | |
| Year 3 | IDR: 200.000.000 | |

Inderalaya, January 2016

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# CHAPTER 1
# INTRODUCTION

## 1.1 Background of the Problem

The environment is becoming more polluted due to the various wastes discharged from a wide range of industrial applications. Rapid growth of the aviation industry has resulted in a significant increase in production, which in turn generates huge amount of undesirable wastes. These reflected the significant needs among the new aircraft, engines and spare parts, which fulfil the manufacturing standards. Machining metal alloy material focal planes on the quality of the machining process. The quality standards affect various processes that associated amongst other methods of manufacturing, machining completeness of such a chisel and a supporting part as coolant machining (Kappmeyer, et al., 2012).

Nowadays, titanium alloy (Ti64) is the material engineering that develops rapidly as an aircraft component material (aerospace material). Titanium has a fatigue strength properties, tensile strength, wear resistance, light weight and corrosion resistance resulting economic feasibility. Ti64 are also widely used in various other fields in addition to the airline industry, among others, the automotive industry, shipping, offshore, military bullet layer, nuclear, chemical vessels, turbines, electrochemical even biomedical implants (Raza, et al., 2014). Ti64 needs more complex machining techniques, but pose a greater challenge in requirement in machining process in accordance with the cost factor of production and use of refrigeration to reduce tool wear and extend to life (Elshwain, et al., 2013).

During the machining process it is often used mineral oil that is made from petroleum fluid as a coolant. But this liquid turned out to be a health risk carrier, expensive and also environmentally unfriendly (Lawal, et al., 2013). In addition, the drawbacks of using a form of gases and cryogenic coolant were relatively expensive because it cannot be reused and can cause brittleness. Many researchers have developed the type of coolant and focused to apply the vegetable oil as a coolant, it's called bio-based coolant that can reuse in the machining processes (Lawal, et al., 2013) (Elshwain, et al., 2013). Modelling and optimization of the variables in the machining process, such as cutting speed, the cutting speed and depth feeds will run using the statistical method of network algorithm terms imitation (artificial neural network (ANN)) and response surface methodology (RSM). The analysed parameters are tool life and surface roughness.

As known, several common techniques have been improved for disposing and pre-treatment alternatives available for non-hazardous water-miscible machine coolant, such as chemical treatment, ultrafiltration systems, evaporators in order to remove soluble and insoluble of organic and inorganic contaminants from machine coolant wastewater. UF membrane technologies have been greatly used in separation facilities to separate liquid/liquid or liquid/solid mixtures due to the suitable pore sizes and capable of removing emulsified oil droplets and other organic contaminants (Lee, et al., 2003); (Rautenbach & Albrecht, 1989); (Takht Ravanchi, et al., 2009); (Pulefou, et al., 2008); (Jiang, et al., 2003). Ultrafiltration is only somewhat dependent upon the charge of the particle and is much more driven by the size of the particle and also is used to separate different fluids or ions. Ultrafiltration is most commonly used to separate insoluble components from the aqueous phase. One of the uses that demonstrates the usefulness of ultrafiltration is separation of oil in an emulsion of water, such as coolant wastewater. In this study, machining coolant emulsions can have the oil separated and concentrated, with the water phase being discharged to sanitary sewer, and the concentrated oil phase being disposed of at a lower cost. However, these methods would lead to a huge production of sludge and complicated operations problems (Galil and Levinsky, 2007); (Judd, 2011); (Kalyandurg, 2003).

Even with the best machine coolant management program, machine coolant will not last indefinitely and will eventually require disposal. Environmental regulations are making disposal increasingly difficult. The waste material must be tested using standard methods or the generator must have sufficient knowledge about the waste to assess whether it is a hazardous waste. View some of our articles in the machine coolant filtration index for more information on machine coolant management and for more information on helping you to reduce costs of disposal and recycling of machine coolant (Yoro Jr, 2010); (Lawal, et al., 2013).

Nowadays the use of vegetable oil as coolant was developed by many researchers (Yoro Jr, 2010); (Lawal, et al., 2013). They found that vegetable oil, such as coconut oil, is a potential suitability coolant in machining industries. In addition, coconut oil is a potential natural resources in South Sumatera Province. Table 1.1 illustrated the potential of coconut in South Sumatera Province in 2008-2013.

Table 1.1 Potential of coconut in South Sumatera Province ( (The Central Statistics Agency of South Sumatra Province, 2015).

| | |
|---|---|
| PRODCTION OF 2013 (TON) | 60.620 |
| PRODUCTION OF 2012 (TON) | 62.532 |
| PRODUCTION OF 2011 (TON) | 67.381 |
| PRODUCTION OF 2010 (TON) | 59.105 |
| PRODUCTION OF 2009 (TON) | 59.035 |
| PRODUCTION OF 2008 (TON) | 71.605 |

On the other hand, there is a branded coconut oil which can found in mini market or supermarket namely Coconut oil Barco. In this study, this type of coconut oil will be used as machine coolant.

## 1.2 Roadmap of Research

Study on machining of aerospace materials has been started in a few years in line with the roadmap of research of mechanical engineering department as shown in Figure 1.1. This research collaboration with Universiti Teknologi Malaysia will work in the fields of product optimization in machining parameters based on geometry, materials, and environmental requirements. For analysing of the environmental problems, it has provided a potential opportunity in using of bio based coolant i.e. Vegetable oil to overcome the problems generated by conventional machining using oil based and water based coolants.

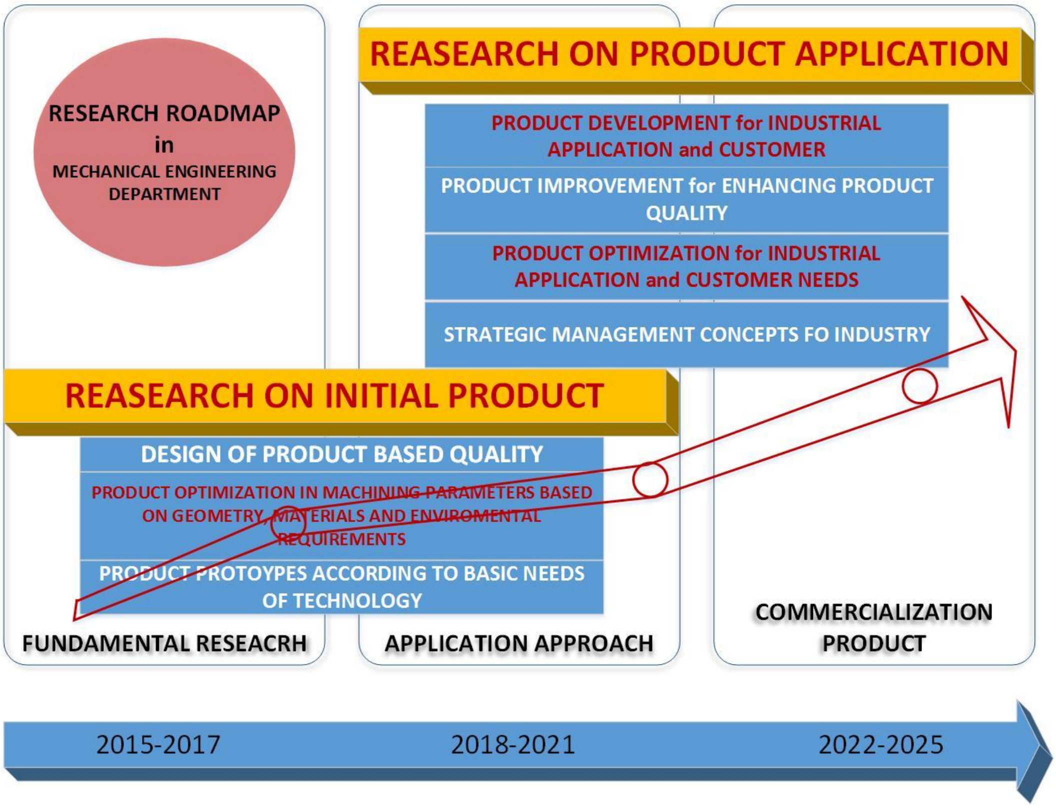


Figure 1.1 Research Roadmap in Mechanical Engineering Department Sriwijaya University

As shown in Figure 1.1, the research frame works divided in two frame works those are research on initial product and research on product application. The use of optimization has been proved to reveal the machining parameters and potential environmental enhancement according to basic needs for recently provided technology.

## 1.3 Objectives

The main objectives of this study are to reveal the machining parameters, which are significantly influencing the product and environment quality using vegetable oils. Modelling and optimization of these parameters will use the statistical method response surface methodology (RSM) and network algorithm in terms of imitation namely artificial neural network (ANN).

To observe the revealed changes of the microstructure of Ti-alloys, Scanning Electron Microscope (SEM) will be used. In order to achieve the requirements of standard environmental regulation, an experimental UF membrane unit for treatment wasted coolants will be developed, which provided the analysing of the membrane surface, flux, permeability and retentive.

In conjunction, the specific objectives of this research are listed below:

1. To evaluate the most significant machining parameters such as cutting speed, feed rate, depth of cut, and type of cutting conditions (dry, minimum quantity lubrication (MQL) and flood machining).
2. To characterize the cutting tools and workpiece based on the machining parameters such as surface roughness, tool life, stress analysing, and microstructure changes.
3. To find the optimum cutting conditions, according to industrial and environmental needs.
4. To identify and quantify the nature of the deposited hazardous materials of wasted coolant.
5. To determine the roles of membrane characteristics on fouling behaviours.
6. To assess the interactions, relationship among contaminant fractions, colloidal particles and membrane properties on fouling characteristics, permeate quality.
7. To assess the relative influence, the magnitude and interrelationship of the key operating factors such as HRT, pH and coagulant dosage on membrane performance.

## 1.4 Scopes of the Study

In this study, it will be investigated the performance of straight carbide tools end mills in the machining of Ti-alloys under dry, MQL and flood cutting condition using vegetable oils (coconut oils) as a potential replacement of traditional lubricants such as mineral oil and water based coolants. This type of coolant indicated the advantages in environmental friendly influences for conventional machining processes so that this process can be classified as green machining.

The potential environmental aspects as wasted coolants will be investigated using membrane technology to separate hazardous materials dissolved in the waste, to minimize environment pollutant or to ensure the wasted coolant discharged safely to the environment. Moreover, it can be reused for other industrial application. Polyvinyl fluoride (PVDF) and lithium chloride will be used in this study as UF-membrane that spun by using a phase inversion technique. The detailed scope of this study is listed below:

1. Optimum cutting conditions of the green machining will be obtained through the experimental data using combined optimization methods namely RSM and ANN.
2. Analysing of cutting tools performance and workpiece characterization will be resulted based on the most significant parameters of machining process.
3. Membrane characterization by flux, contact angle, hydrophobicity, functional groups (FTIR), and morphology (SEM).
4. The wasted coolant will characterize by dissolved organic carbon (DOC) and pH.
5. The performance of UF membrane will measure through permeate quality, DOC rejection and flux decline.

## 1.5 Study Outcomes

This study will produce few outcomes as listed below:

1. Published in international journals with impact factor or minimum indexed by Scopus, such as Journal of Materials Processing and Technology, Journal of Advanced Materials Research, Journal of Applied Mechanics and Materials, Journal of Separation and Purification, Journal of Membrane Science, Desalination, Jurnal Teknologi.
2. Optimized machining parameters are expected to reduce the machining costs.
3. Membrane systems for separating coolant disposal affected on the minimizing of environmental pollutant.
4. Book chapter will produce to support the additional knowledge of machining process and membrane technology.

## 1.6 Significance of Study

This research is conducted to provide the optimum machining process condition using coconut oils and also quantitatively and qualitatively with an integrated understanding on environmental effect of machining processes.

The characteristics of coolant disposal properties which are potentially becoming primary foulants that would result in severe flux decline are investigated.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 Introduction to Metal Cutting

Cutting process involves the removal of work material by chip forming operations known as machining process. The term metal cutting is commonly associated with big industries (automotive, aerospace, home appliance, etc.), that manufacture big products. Turning, milling and drilling are the principal metal cutting processes and they are the most commonly used machining processes in many industries (Trent and Wright, 2000).

## 2.2 End Milling

In milling processes, material is removed from the workpiece by a rotating cutter. The two basic milling operations are peripheral (or plain) milling and face (or end) milling as shown in Figure 2.1. Peripheral milling generates a surface parallel to the axis of rotation, while face milling generates a surface normal to the axis of rotation. Face milling is used for relatively wide flat surfaces (usually wider than 75 mm). End milling, a type of face milling operation, is used for facing, profiling, and slotting operations.

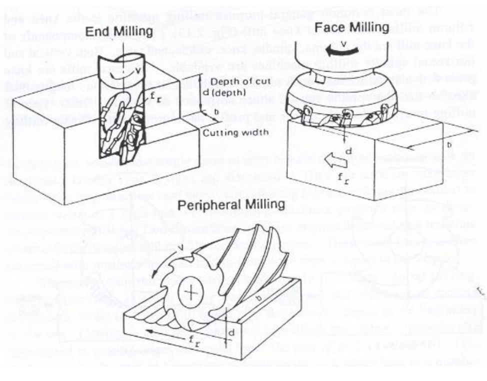


Figure 2.1 Type of milling operation (Stephenson and Agapiou, 1997)

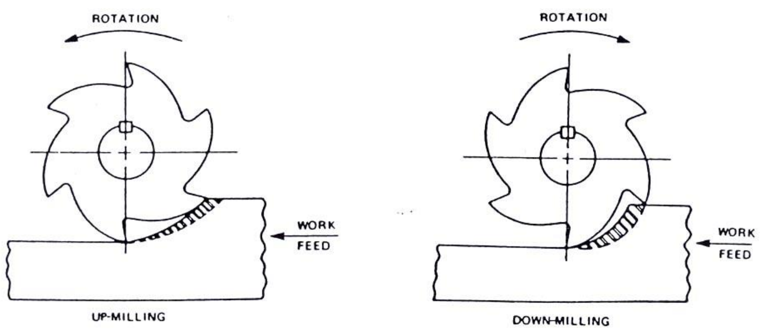


Figure 2.2 Schematic view of the up- and down milling approaches (Stephenson and Agapiou, 1997)

Milling processes can be further divided into up milling or conventional and down milling or climb operations shown in Figure 2.2. In up milling, the axis of the cutter do not intersect with the workpiece and the motion of cutter rotation opposes the feed motion. Down milling occurs, when the motion of cutter rotation is in the same direction of the workpiece. When the axis of the cutter intersect the workpiece, both up and down milling occur at different stage of rotation. Up milling is usually preferable to down milling when the spindle and feed drive exhibit backlash and when the part has large variations in height or a hardened outer layer due to sand casting or flame cutting. In down milling, there is a tendency for the chip to become wedged between the insert and cutter, causing tool breakage. However, if the spindle and drive are rigid, cutting forces in peripheral down milling tend to hold the part on the machine and reduce cutting vibrations.

## 2.3 Cutting Tools

Cutting tool design has strong impact on machining performance. Properly designed tool produce parts of consistent quality and have long and predictable useful lives. Improper designed tool may wear or chip rapidly or unpredictable, reducing productivity, increasing cost and producing parts of deteriorating quality.

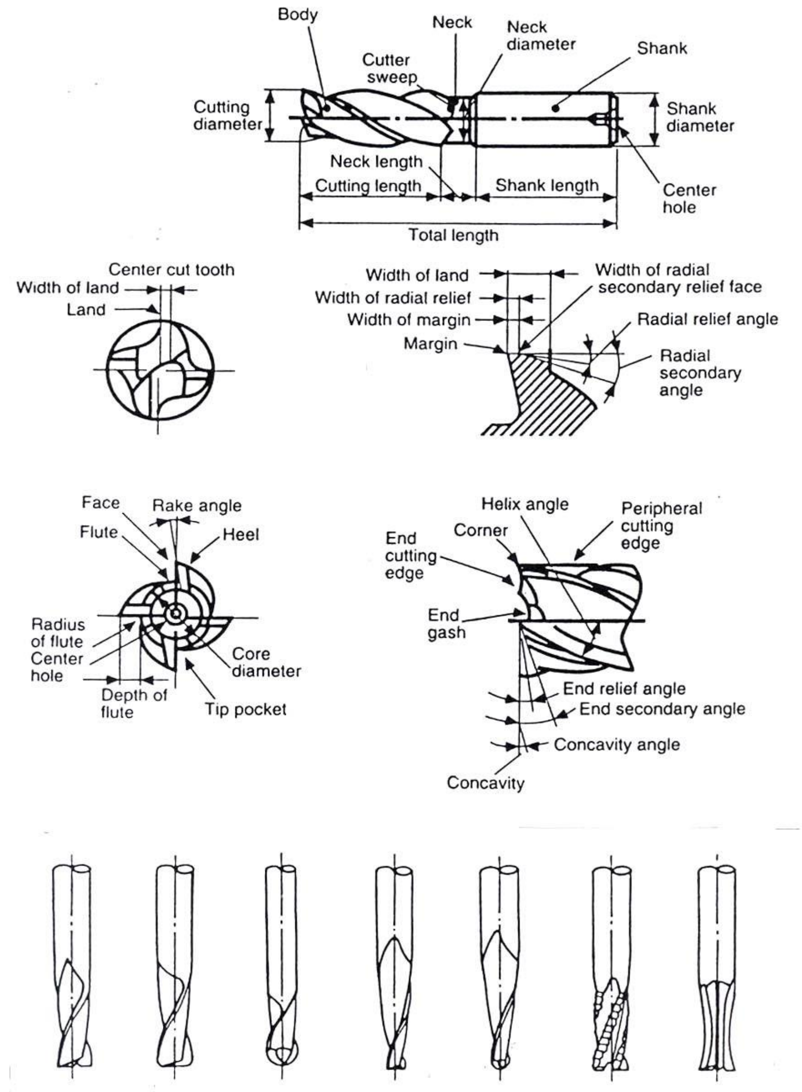


Figure 2.3 End mill geometry (Stephenson and Agapiou, 1997).

Cutting tool may be broadly classified as single point tools, which have one active cutting edge, and multipoint tools, which have multiple active cutting edges. Single point tools are commonly used for turning and boring, while multipoint tools are used for drilling and milling. Tools may be further classified based on the cutting edge material, geometry, and clamping method. The best choice of tool material and geometry in a given operation depends on the volume of parts to be machined, the workpiece material, the required accuracy, and the capabilities of available machine tools (Paucksch, 1996); (Stephenson and Agapiou, 1997); (Trent and Wright, 2000); (Shaw, 2005).

The end milling process uses a special type of tool known as end mill. The end mill comes in various forms and types with special geometry as shown in Figure 2.3.

## 2.4 Machining of Titanium Alloys

Titanium alloys are metals that contain a mixture of titanium and other chemical elements. Such alloys have very high tensile strength and toughness (even at extreme temperatures). They are light in weight, have extraordinary corrosion resistance and the ability to withstand extreme temperatures. However, the high cost of both raw materials and processing limit their use of military applications, aircraft, spacecraft, medical devices, highly stressed components such as connecting rods on expensive sports cars and some premium sports equipment and consumer electronics.

Although "commercially pure" titanium has acceptable mechanical properties and has been used for orthopaedic and dental implants, for most applications, titanium is alloyed with small amounts of aluminium and vanadium, typically 6% and 4% respectively, by weight. This mixture has a solid solubility, which varies dramatically with temperature, allowing it to undergo precipitation strengthening (Raza, et al., 2014). This heat treatment process is carried out after the alloy has been worked into its final shape, but before it is put to use, allowing much easier fabrication of a high-strength product.

As mentioned above, Ti-alloys, particularly $\alpha + \beta$ alloys such as Ti-6Al-4V (Ti64), have been the focus of considerable research recently, because of their excellent fracture toughness, extensive ductility, corrosion resistance and high specific strength to weight ratio ($E/\rho$), which is even maintained at elevated temperatures (250 $^{o}$C – 600 $^{o}$C). These properties make Ti-alloys the most attractive metallic materials for metal working, aeronautic industry, chemical industry, marine environments, and biomaterials applications (El-Morsy, 2009); (Corduan, et al., 2003). On the other hand previous studies have shown that titanium alloys are considered as the difficult to machine materials because of its low thermal conductivity, its high heat capacity and high chemical reactivity, regardless of the type materials used (Koenig, 1979); (Calamaz, et al., 2009); (Arrazola, et al., 2009). To overcome such situation, the optimum cutting conditions play a significant role in the machining of difficult to cut materials. One of the optimum cutting conditions that result in the best tool performance using RSM was reported by (Mohruni, et al., 2007). Another investigation was carried out by (Reddy and Rao, 2006) and (Jain, et al., 2007) using genetic algorithms for machining processes. They reported that a genetic algorithm can be utilized for investigating the optimum machining conditions. None of the previous studies were focused for optimizing of cutting conditions on aerospace materials using a combination of ANN and RSM. This challenge was taken into consideration in this study, to fill the lack of information in this field. Therefore, further investigation of the utilization of these algorithms, was employed for optimizing of machining conditions on titanium alloys.

## 2.5 Coconuts Oils as Coolants

Coconut oil has a long shelf life compared to other oils, lasting up to two years due to its resilience to high temperatures. Coconut oil is best stored in solid form, at temperatures lower than 24.5 $^{o}$C (76 $^{o}$F) in order to extend shelf life. However, unlike most oils, coconut oil will not be damaged by warmer temperatures. Fractionated coconut oil “is a fraction of the whole oil, in which most of the long-chain triglycerides are removed so that only saturated fats remain. It may also refer to as “caprylic/capric triglycerides” or medium-chain triglyceride (MCT) oil because mostly the medium-chain triglycerides caprylic and capric acid are left in the oil. Because it is completely saturated, fractionated oil is even more heat stable than other forms of coconut oil and has a nearly indefinite shelf life (Kuram, et al., 2013).

Refined coconut oil is referred to in the coconut industry as RBD (refined, bleached, and deodorized) coconut oil. The starting point is “copra”, the dried coconut meat. Copra can be made by smoke drying, sun drying, or kiln drying. The unrefined coconut oil extracted from copra called “crude coconut oil” is not suitable for consumption and must be refined (Kuram, et al., 2013).

Coconut oil (CNO) production accounts for 57% of world’s lauric oil output. This implies that the number of bearing palms in the country is abundant in terms of supply in the production of coconut oil and is therefore enough for the processes of coconut cutting fluid (Kuram, et al., 2013).

Coconut oils are used in the processing and distributed in the different products as raw material. Production of food products such as margarine, shortenings and filled milk and the manufacture of soap, detergents, toilet articles, shampoos and cosmetic industries, both for local and international markets consume 40% of the total coconut oil demand. The Production of plasticizers, pharmaceutical products, fatty alcohol, fatty acids and fuel has an 18% share in the total production. While 3% is used domestically either in the household and other needs (Kuram, et al., 2013).

Table 2.1 Advantages and disadvantages of vegetable oils as lubricants (Shashidhara and Jayaram, 2010).

| Advantages | Disadvantages |
|---|---|
| High biodegradability | Low thermal stability |
| Low pollution of the environment | Oxidative stability |
| Compatibility with additive | High freezing points |
| Low production cost | Poor corrosion protection |
| Wide production possibilities | |
| Low toxicity | |
| High flash points | |

Vegetable oils are particularly effective as boundary lubricants as the high polarity of the entire base oil allows strong interactions with the lubricated surfaces. (Belluco and De Chiffre, 2001) evaluated the performance of a range of mineral and vegetable oil-based cutting fluids in a wide range of machining operations and found that vegetable-based oil formulations displayed equal or better performance than the reference commercial mineral oil in all operations. In summary, vegetable oils do display many desirable characteristics, which make them very attractive lubricants for many practical applications. Table 2.1 shows the advantages and disadvantages of vegetable oils as metalworking fluids.

### 2.5.1 Chemical Properties

Coconut oils consist of about 90% saturated fat. The oil contains predominantly medium chain triglycerides, with 86.5% saturated fatty acids, 5.8% monounsaturated fatty acids, and 1.8% polyunsaturated fatty acids. In the saturated fatty acids, coconut oils are primarily 44.6% lauric acid, 16.8% myristic acid and 8.2% palmitic acid, although it contains seven different saturated fatty acids as oleic acid while its only polyunsaturated fatty acid is linoleic acid. The unrefined coconut oil melts at 20-25°C and smokes at 170°C (350°F). Refined coconut oil, meanwhile, has a higher smoke point of 232°C (450°F).

Coconut oil has a long shelf life compared to other oils as shown in Table 2.2, lasting up to two years due to its resilience to high temperature. Coconut oil is best stored in solid form at a temperature lower than 24.5°C (76°F) in order to extend shelf life. However, unlike most oils, coconut oil will not be damaged by warmer temperatures (Shashidhara and Jayaram, 2010). This implies that coco oil is feasible materials for cutting fluid because of the presence of the chemical properties found in them.

Table 2.2 Comparative information of cutting fluids (Yoro Jr, 2010).

| Material Component | Synthetic (Chemical Oils) | Coco Oil (Natural Oils) |
|---|---|---|
| Type | Emulsifiable | Emulsifiable |
| Efficiency | Highly Efficient | Efficient |
| Uses/Application | General Machining | General Machining |
| Effect to human skin | Irritant (if not used properly) | Non-Irritant (if not used properly) |
| Effect on disposal | Negative effect to the environment | Environment friendly |
| Cost | P1, 550.00*/litre | P1, 550.00*/litre |

Table 2.3 Efficiency of coconuts cutting fluids (Yoro Jr, 2010).

| Treatment | Rating average | | | Total | Average mean |
|---|---|---|---|---|---|
| | Drilling | Grinding | Turning | | |
| 1 | 4.75 | 4.5 | 4.5 | 13.7 | 4.58 |
| 2 | 3 | 3 | 3 | 5.9 | 3 |
| 3 | 2.5 | 2.5 | 2.5 | 7.5 | 2.5 |
| 4 | 2.75 | 2.75 | 2.75 | 8.25 | 2.75 |

Table 2.3 presented the efficiency of coco cutting fluid by (Yoro Jr, 2010). To measure and evaluate the efficiency of the four treatments, a group of invited ten (10) instructors and ten (10) selected students were made to observe, evaluate and rate according to emulsion stability, lubricity, quality finish and tool life. Each treatment was used and applied as cutting fluid in drilling, grinding and turning. Ratings were recorded and interpreted statistically.

## 2.6 Membrane Definition

Membrane filtration process involving microfiltration (MF), ultrafiltration (UF), Nano-filtration (NF) and reverse osmosis (RO) play an increasing role as unit operations for resource recovery, pollution prevention, energy production, environmental protection and public health (Hammer and Hammer Jr., 2008). They have increased rapidly in the past decade in numerous industrial applications such as treatment for potable water production, industrial effluent remediation, seawater desalination, softening, gas separation process, liquid food treatment, fuel cell development and biotechnology separation. The stream passing through the membrane is called permeate while the rejected material is termed as retentate. A general description of membrane separation processes is shown in Figure 2.4. Apparently, a membrane is a selective barrier between two fluid phases which is able to transport certain chemical components more readily than the others based on differences in their physical and chemical properties (Mulder, 1991).

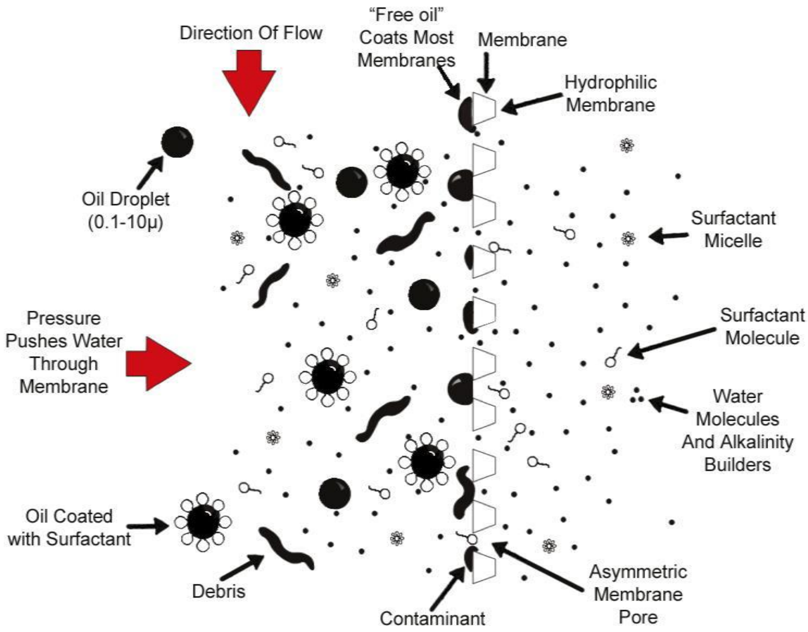


Figure 2.4 Schematic diagram of membrane filtration (Mulder, 1991).

### 2.6.1 Membrane Classifications

Membranes are classified by their operational driving forces (pressure gradient, concentration gradient, electrical potential difference and temperature), types of separation (solid-liquid or gas-liquid separation), separation mechanisms, natural or synthetic, chemical nature (solid, liquid or gas), configuration, morphological characteristics (porous or non-porous) and geometry. The pressure-driven membrane separation processes are generally categorized into four groups depending on the membrane pore size and separation mechanisms: microfiltration (MF), ultrafiltration (UF), Nano-filtration (NF) and reverse osmosis (Mulder, 1991).

### 2.6.2 Factors Affecting Membrane Characteristics

In general, membrane fabrication involves trial-and-error method which covers optimal material formulation, selection of critical operating variables and proper conditions during fibre spinning. Although a great deal of works has been carried out in the past, but still fabrication of membrane for specified application is extremely difficult. Asymmetric polymeric membrane fabrication has been intensively focusing on phase inversion processes (Pinnau, et al., 1993); (Ismail, et al., 2008). (Pesek and Koros, 1993) revealed that the selectivity of membrane is subfibreially influenced by the fibefluid up rates and the bore fluids salt concentrations.

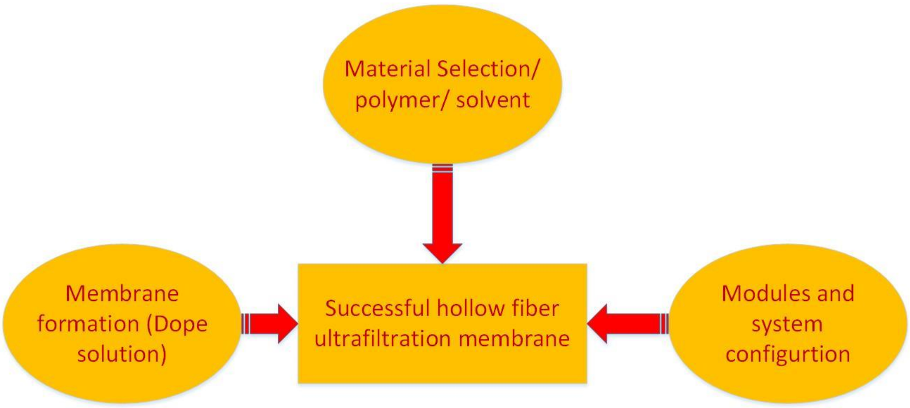


Figure 2.5 Controlling factors in ultrafiltration fabrication (Wienk, et al., 1995).

These parameters have been found to improve with the increment of dope extrusion rate. However, the elongation factor showed an adverse effect to membrane selectivity although permeability exhibited positive improvement. In addition, (Wienk, et al., 1995) also describe that the rheological parameters such as shear, die-swell and air gap residence time are the important factors in controlling the membrane morphology as well as its performance. Membrane morphology can be classified into symmetrical and asymmetrical membranes. Symmetrical membrane has the same porosity across the membrane, whereas the asymmetrical consists of two different layers. The top layer of asymmetrical membrane is denser and has selected while the supporting layer is more porous with less resistance. As the mass transfer resistance increases with membrane thickness, therefore the development of asymmetric membrane resulted in a significant reduction in membrane effective thickness. Symmetrical membrane has thickness ranges from 10 µm to 2000 µm while the asymmetry is normally found with a skin layer of 0.1 µm to 0.5 µm and a porous support layer of 50 µm to 150 µm.

## 2.7 Membrane Reactor

Membrane filtration was initially employed as tertiary treatment or as refining stage in wastewater plants. Membranes like UF, MF or RO were applied as a polishing step (Metcalf & Eddy Inc., et al., 2003). But the emergence of less expensive and more effective membrane modules initiated a new concept of application in both wastewater and water treatment systems. There are several advantages associated with membrane reactor treatment systems which make them a valuable option over other treatment techniques. This configuration is able to retain all suspended matter and most soluble compounds leading to excellent effluent quality. For wastewater treatment applications, the system is known as membrane bioreactor (MBR) and was initially used for municipal wastewater treatment, primarily in the area of water reuse and recycling. Compactness, a small footprint, production of reusable water, reliable, particulate free effluent, less excess sludge due to increased sludge age, high efficiency due to higher biomass concentration and practical made MBR an ideal process for recycling. Membrane circulated in bioreactor is shown in Figure 2.6 and Figure 2.7.

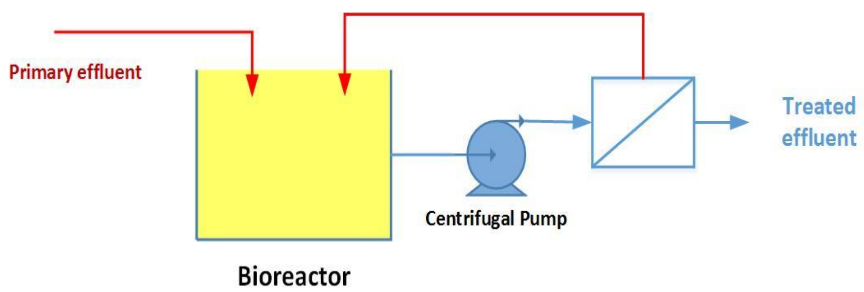


Figure 2.6 Ultrafiltration membrane circulated in bioreactor (Judd, 2011).

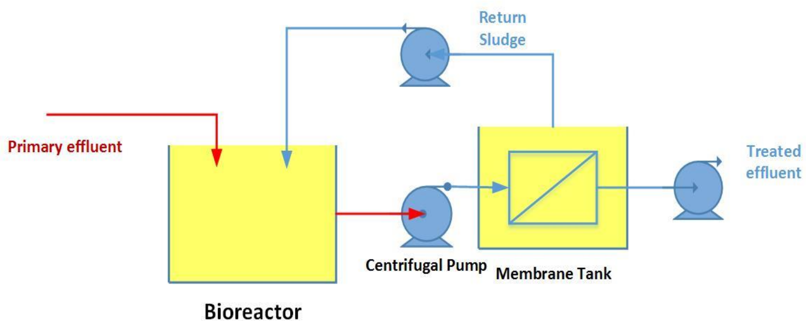


Figure 2.7 Ultrafiltration membrane immersed in external tank (Judd, 2011).

## 2.8 Coolant Contaminant Removal

Coolants are most frequently contaminated by chips and fines, tramp oil, bacteria and dissolved salts. Chips and fines are removed from coolants to eliminate surfaces for bacteria to grow on. Free oils are removed to eliminate a food source for bacteria and surface films that prevent oxygen from dissolving into the coolant. Dissolved salts are removed because they affect tool and coolant life, foaming characteristics, filtering efficiency and emulsion stability. By removing these contaminants, machining facilities can reduce costs by prolonging the effective life of coolants. A good first step is teaching machine operators not to use coolant sumps as trash receptacles. Waste food, cigarettes and other trash are sources of bacterial contamination and feed bacterial growth. A variety of equipment is available for removing or managing the four most frequent contaminants: chips and fines, tramp oil, bacteria and dissolved salts. The table at the end of this fact sheet describes the equipment and techniques used to remove or control these contaminants.

Table 2.4 Equipment and technique used to remove contaminants (Minnesota Technical Assistance Program (MTAP), 2015).

| Contaminant | Control method | Contaminant Removal Process |
|---|---|---|
| Metal chips and fines | Bag and cartridge filters | Over time, small chips and metal fines accumulate and settle in coolant sumps. Coolants should be filtered routinely to remove these contaminants. Usually a 50-micron bag filter is used, followed by a 10- or 5-micron cartridge filter. |

| Contaminant | Control method | Contaminant Removal Process |
|---|---|---|
| | Centrifuges | With high-speed centripetal force, centrifuges can separate very fine and suspended particles from coolant |
| | Hydro cyclones | Hydro cyclones help concentrate solids from a coolant. With coolant entering at high speed, the conical shape of a hydro cyclone draws clean coolant flow upward and forces heavy solids flow downward. Solids are then removed by filtration. |
| | Screens and conveyors | Placing metal screens and drag conveyors at coolant sumps will collect the majority of metal chips and turnings. |
| Tramp oil | Belt and disk skimmers | Used to skim off tramp oils floating on the surface of the coolant, skimmers are designed to fit on top of settling tanks or accessible machine sumps |
| | Coalesces | Coalesces contain a series of plates that allow tiny oil droplets to cling together, causing the oil to rise at a faster rate, increasing the amount of oil removed. |
| | Settling tanks | A settling tank provides a calm environment and ample time for tramp oil to rise to the surface of the coolant. Tramp oil can then be removed using a skimmer. Baffles within a tank help localize tramp oil for more efficient removal |
| Bacteria (anaerobic) | Aeration | Aeration is the simplest method to control the growth of anaerobic bacteria. Aeration creates an oxygen-rich environment, preventing anaerobic conditions and the growth of anaerobic bacteria. Non-aerated coolant sumps provide ideal conditions for the growth of anaerobic bacteria: water and no oxygen. Anaerobic bacteria break down sulphur-containing compounds in coolants, and generate acidic hydrogen sulphide (H2S) gas, recognizable by a "rotten egg" smell. If bacterial growth is not controlled in the coolant, the H2S can impede its lubricating qualities and can create a corrosive environment that could damage tools and parts. Aeration is accomplished by recirculating the coolant in the sump when the machine is not in operation, or by adding a stirring mechanism or an air bubbler to the sump. |
| | UV light, ozone, heat pasteurization and chemical biocides | Many other methods are available to control bacterial growth problems. When selecting one, determine if it is compatible with the coolant used and if it will control the bacterial strains present. Coolant suppliers can help determine which method to use for specific applications. Add chemical biocides only when needed. Excess biocide can cause coolant pH to fluctuate and can have an adverse effect on human health, such as aggravated dermatitis. As a last resort for controlling bacterial growth, use an EPA-approved chemical biocide |
| | Sump cleaning | Routine sump cleaning controls bacterial growth. When a coolant is replaced, the sump should be |

| Contaminant | Control method | Contaminant Removal Process |
|---|---|---|
| | | chemically or steam cleaned to remove any residual bacteria that could contaminate the new coolant. |
| Dissolved salts | Water treatment: deionization, reverse osmosis, or distillation | City or well water usually contains significant amounts of calcium and magnesium causing hard water. It may also contain other minerals and possibly some suspended solids. These contaminants affect tool and emulsion stability. As coolant life is extended, these contaminants build up. Hard water minerals can cause scaling on equipment and upset the chemical balance of the coolant. Suspended solids provide surfaces for bacterial growth and can place abrasive solids in the cutting zone. Water softening is not a useful treatment method because it introduces sodium salts, which can be corrosive when combined with chlorides and sulphates in the coolants |

# CHAPTER 3
# RESEARCH METHODOLOGY

## 3.1 Design of Experiment (DOE)

The objective of the design of experiment (DOE) is to provide an efficient means of experimentation and analysis of experimental results. The statistical design of experiments has been used by several researchers in the analysis of machining process (Wu, 1964); (Lo and Chen, 1977); (Balakrishnan and DeVries, 1983); (Balakrishnan and DeVries, 1985); (Alauddin, 1993); (Alauddin, M., et al., 1996); (Alauddin, M, et al., 1996); (Alauddin and El Baradie, 1997); (Alauddin, M, et al., 1996A); (Choudhury and El-Baradie, 1998); (Choudhury and El-Baradie, 1999); (Mansour and Abdalla, 2002); (Noordin, et al., 2004); (Reddy and Rao, 2005); (Sahin and Motorcu, 2005). The methodology adopted in these investigations is of recent origin and it has been demonstrated that statistical design of experiments is very economical and the analysis of the data leads to accurate and reliable conclusions.

The salient features of experimental designs for exploring response surface have been discussed by many authors (Box & Wilson, 1951) (Box, et al., 1978) (Myers & Montgomery, 2002) (Myers, et al., 2004) (Montgomery, 2005). The following properties are desirable for a sound experimental design:

5. The design should allow the approximating polynomial of degree “n” to be estimated with satisfactory accuracy within the region of interest.
6. It should allow a check to be made on the representational accuracy of the assumed polynomial.
7. It should not contain an excessively large number of experimental points.
8. It should lend itself to blocking.
9. It should form a nucleus from which a satisfactory design of order “n+1” can be built in case the polynomial of degrees “n” proves inadequate.
10. The design should provide an economical and reliable means of experimentation.

11. Every design need not possess all the properties mentioned above. The relative importance of the properties depends on the particular experimental conditions.

## 3.2 Response Surface Methodology

Usually, the relationship between the dependent variables and the independent variables is too complex or unknown. Response Surface Methodology, or RSM, provides a procedure, which solves this problem. It is a collection of mathematical and statistical techniques useful for the modelling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response (Montgomery, 2005).

The most extensive applications of RSM are in the industrial world, particularly in situations where several input variables potentially influence some performance measure or quality characteristics of the product or process. This performance measure or quality characteristic is called response (Myers & Montgomery, 2002).

### 3.2.1 The Response Function and the Response Surface

It is assumed that the designer is concerned with a system involving some response variables y, which depends on the input variables $x_i$. It is also assumed that $x_i$ is continuous and controllable by the experimenter with negligible error and only quantitative variables can be included in the predicted models. However, by building a number of the qualitative variables models, their effect can also be studied. The response is to be a random variable.

The functional relationship between the measured (observed) response and the independent variables can be expressed as:

$$y = f(x_1, x_2, x_3, ..., x_k) + \varepsilon' \quad (3.1)$$

where $y$ – the level of measured (experimental) response

$f$ – the response function

$x_i$ – the level of independent variables or factors

$\varepsilon'$ – the experimental error.

Knowledge of response function gives a complete summary of the results and enables in predicting the response for the value of factors that were not tested experimentally (Box, et al., 1978). The predicted response is denoted by $\hat{y}$, which would be obtained in the absence of experimental error and is given by:

$$\hat{y} = y - \varepsilon' = f(x_1, x_2, x_3, \ldots, x_k). \tag{3.2}$$

The surface generated by $\hat{y}$ is called the response surface. This surface can be presented in 2D contour or 3D surface, which is very helpful in interpreting the results of experimentation.

### 3.2.2 Representation of the Response Surface by The Contours

As mentioned above the response surface is useful for interpreting the results of experimentations, which represented the relationship between a response and the independent variables. A mesh surface generated by $\hat{y}$ is usually used in maps to show maximum and minimum values, which can be achieved by the relationship among the independent variables. In certain cases, in combination with another $\hat{y}$ function, the optimum conditions can be found. Thus, the finding of the optimum conditions is commonly preferred as the final compromise solution of particular boundary conditions.

As initial approach, the first order (linear) model is commonly used to find the solutions, which fulfil the cutting conditions. Further approach is the second order (quadratic) model, which is generated to cover more complex cutting conditions required in finding the optimum conditions. In this approach, it is possible to find the maximum or minimum values. The occurrence of hyperbolas implies that there is a saddle point (at which the response is a minimum for one direction and a maximum for other direction) somewhere on the response surface (Figure 2.1). The projection of response surface from 3D into 2D is called response contours (Figure 2.2)

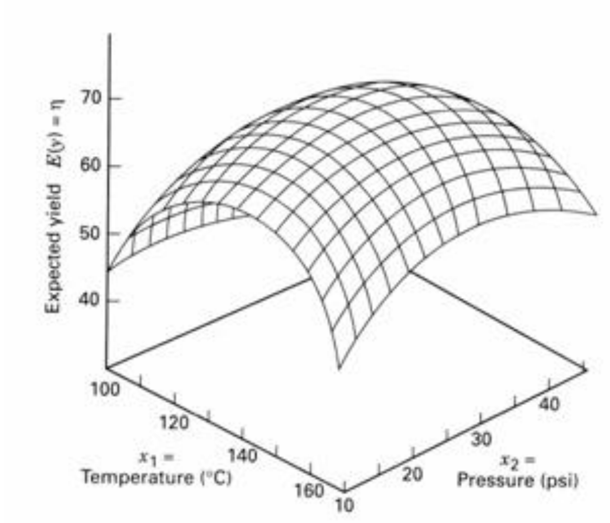


Figure 3.1 A three dimensional response surface showing the expected yield (η) as a function of temperature ($x_1$) and pressure ($x_2$) (Myers & Montgomery, 2002).

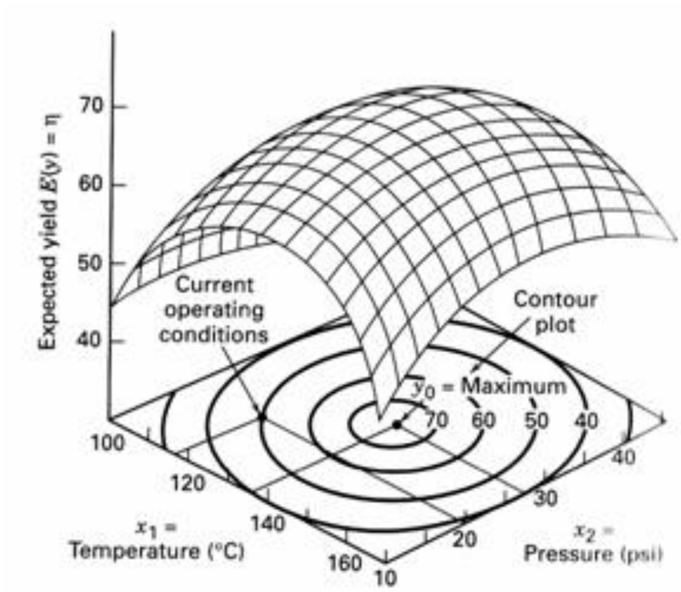


Figure 3.2 A contour plot of response surface (Myers & Montgomery, 2002).

## 3.3 Central Composite Design (CCD)

A central composite design (CCD), originally proposed by (Box & Wilson, 1951) has been used in this investigation. The factors investigated or independent variables were cutting parameters of the cutting tools and applied cooling systems such as cutting speed, feed per tooth, axial and radial depth of cut under dry, MQL system. As the responses or dependent variables were tool life, surface roughness, and cutting force. In order to investigate the effect of the type of tools, thus the rotatable CCD design of experiments was repeated for each type of tool, which are uncoated tool and coated tool.

## 3.4 Coding of the Independent Variables

There are some transformations (coding of independent variables) commonly used in machining research, the first logarithmic transformation is suggested by the majority of previous researchers (Balakrishan & De Vires, 1983) (Alauddin, 1993) (Alauddin & El-Baradie, 1996) (Alauddin & El-Baradie, 1997) (Alauddin, et al., 1996a) (Alauddin, et al., 1996b) (Choudhury & El Baradie, 1998) (Choudhury & El-Baradie, 1999) (Mansour & Abdalla, 2002) (Sahin & Motorcu, 2005) as follow:

$$x = \frac{\ln x_n - \ln x_{n0}}{\ln x_{n1} - \ln x_{n0}} . \tag{3.3}$$

where x = the coded value of any factor corresponding to its natural value $x_n$, $x_{n1}$ = the natural value of the factor at the level +1 and $x_{n0}$ = the natural value of the factor corresponding to the base or zero level.

The second logarithmic transformation was proposed by (Reddy & Rao, 2005a) (Reddy & Rao, 2005b), as follows:

$$x = \frac{\ln x_n - \ln x_{nm}}{\ln x_{nm} - \ln x_{nl}} . \tag{3.4}$$

where $x$ is the coded value of any factor corresponding to its natural value $x_n$, $x_{nm}$ is the natural value of the factor at the medium level and $x_{nl}$ is the natural value of the factor corresponding to the low level.

The third logarithmic transformation was reported by (Wu, 1964) (Lo & Chen, 1977), as follow:

$$x = \frac{2(\ln x_n - \ln x_{n1})}{(\ln x_{n1} - \ln x_{n-l})}. \tag{3.5}$$

where $x$ = the coded value of any factor corresponding to its natural value $x_n$, $x_{n1}$ = the natural value of the factor at the level +1 and $x_{n-1}$ = the natural value of the factor corresponding to the level -1.

## 3.5 Materials and Methods in Membrane Filtration

A PVDF ultrafiltration membrane with an effective area of 0.11 $m^2$ was used in the process tank and a constant TMP (250 mmHg) was maintained to extract the flocculated water from the outside to the inside of the membrane fibres. The flux decline would be expected to increase in the course of time due to membrane fouling, thus the operational permeate flux was monitored over the time to determine the degree of membrane fouling to membrane permeability. The parameters used to quantify the efficiency of membrane processes are flux ($J$), permeability and solute rejection ($R$), where the flux is defined as:

$$J = \frac{Q}{A}. \tag{3.6}$$

where $Q$ is the permeate flow rate (L. $hr^{-1}$) and $A$ is the effective membrane area ($m^2$).

and permeability as:

$$\text{Permeability} = \frac{Q}{A\Delta P} = \frac{Q}{N\Delta P d l \pi}. \tag{3.7}$$

where $\Delta P$ is the transmembrane pressure (Pa), N is the fibre quantity, *d* is the membrane outer diameter (*OD*) and *l* is the membrane effective length (m), the rejection (R %) as:

$$\text{R (\%)} = \left[1 - \left(\frac{C_p}{C_f}\right)\right] \times 100 . \tag{3.8}$$

where $C_p$ is the permeate concentration in mg/L and $Cf$ is the feed dissolved organic compound (*DOC*) concentration (mg/L) measured by *the DOC analyser* (Shidmadzu *TOC-VE*).

With optimal coagulant dosing, pH adjustment, appropriate SUVA and proper FRT, the evolved suspended pin-sized flocs (instead of settle able pin-sized flocs) could be effectively rejected by the 68 kDa MWCO PSF membrane, resulting in higher NOM removal with reasonable flux rate. This may also lead to lower operating costs associated with lesser coagulant consumption and sludge production, and shortened operation time as sedimentation process was eliminated.

## 3.6 Design and Fabrication of Ultrafiltration Membrane Unit

An ultrafiltration membrane pilot plant was set up to treat natural and synthetic surface waters. The experimental setup is schematically illustrated in Figure 3.3. The unit was designed from high quality PVC materials, glass and stainless steel for all wetted parts to prevent corrosion contamination as well as to establish high equipment practicality and reliability. The system comprises the following specifications:

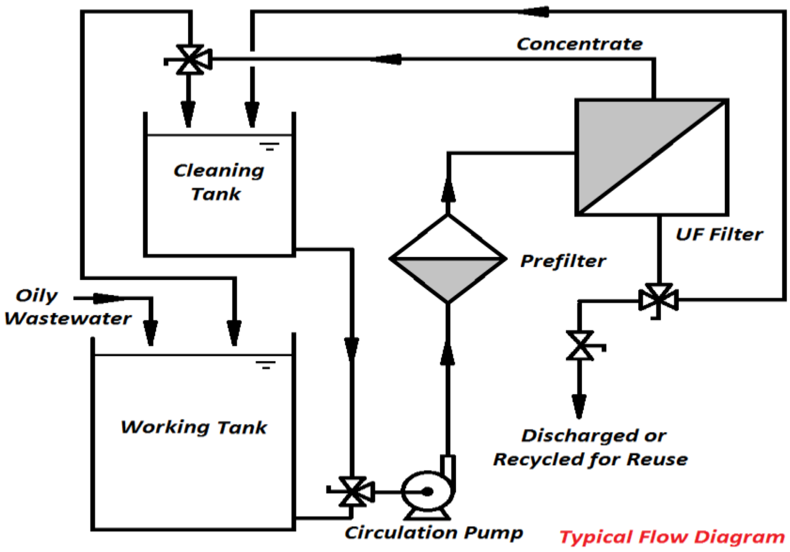


Figure 3.3 Schematic diagram of UF membrane unit

1. Unit tank with maximum working volume of 40 L with dimension of (*h*=1.00m, *w*= 0.15m, *l*= 0.30m).
2. Compressor which supplies air diffuser scouring bubbles flow rate up to 40 L. $min^{-1}$
3. The permeate pump to create a negative TMP pressure.
4. A submerged membrane to supply the filtration media with specified area.
5. Feed tank of 40 litre capacity.
6. Permeate vessel to collect permeate.
7. A back-wash system at the opposite flow direction to eliminate foulants.
8. Flow control valves to regulate the flow of permeate.
9. Flow meters to record the flow rate of permeate.
10. Pressure gauges to record the pressure of the feed.
11. Floating ball to control water level.

## 3.7 Analysis of Data

The morphology of the membrane was observed by field emission scanning electron microscope (FESEM) (JEOL JSM-6700F). The FESEM micrographs were taken at certain magnifications. It produced photographs at the analytical working distance of 10 nm. Surface composition analysis was carried out on energy dispersive x-ray (EDX) (JEOL JSM-6380LA).

The static contact angle of membrane was measured by the sessile drop method using a Drop Meter A-100 contact angle system (Maist Vision Inspection & Measurement Co. Ltd.) to characterize the membrane wetting behaviour. A water droplet at 3 µL was deposited on the dry membrane using a micro-syringe. A microscope with a long working distance 6.5x objectives was used to capture micrographs.

Asymmetric porous membranes were characterized by determination of porosity and average pore radius. The membrane porosity, ε, was defined as the volume of the pores divided by the total volume of the porous membrane. The membrane porosity was calculated using the following equation,

$$\varepsilon = \frac{\frac{(w_1 - w_2)}{\rho_w}}{\frac{(w_1 - w_2)}{\rho_w} + \frac{w_2}{\rho_P}} \times 100\,. \qquad (3.9)$$

where $\varepsilon$ is the porosity of the membrane (%), $w_1$ the weight of the wet membrane (g), $w_2$ the weight of the dry membrane (g), $\rho_p$ the density of the polymer (g/cm$^3$) and $\rho_w$ is the density of water (g/cm$^3$).

To prepare the wet and dry membranes, five spun hollow fibres with the length of 25 cm were selected after solvent was exchanged in tap water for 3 days. The fibres were immersed into the isopropanol for 3 days and distilled water for 3 days. The water remained in the inner surface was removed using air flow, before weighing the membranes. The wet membranes were dried in a vacuum oven for 12 h at 40 $^o$C and weighted.

Average pore radius, $r_m$, was investigated by the filtration velocity method, which a measurement of the ultrafiltration flux of the wet membrane applied to pure water in limited time (20 h) under 0.1 MPa pressure. It represents the average pore size along the membrane thickness (*l*), which was measured by the difference value between external radius and internal radius of the hollow fibre membrane. The test module containing 60 fibres with the length of 35 cm was used to determine water permeability. According to Guerout-Elford-Ferry equation, $r_m$ could be calculated:

$$r_m = \sqrt{\frac{(2.9 - 1.75\varepsilon) \times 8\eta l Q}{\varepsilon \times A \times \Delta P}} \ . \tag{3.10}$$

where $\eta$ is water viscosity (8.9 x $10^{-4}$ Pa s), $\ell$ is the membrane thicoperating, $\Delta P$ is the operation pressure (0.1MPa), $\varepsilon$ is the porosity of ththe volumerane (%), $Q$ is volume of permeate water per unitthe effective area, $A$ is effective area of membrane ($m^2$).

The permeation flux and rejection of PVDF hollow fibre membranes were measured by submerged ultrafiltration experimental equipment as shown in Figure 3.3. An in-house produced U-shape hollow fibre module, with a filtration area of 11.42 $cm^2$, was submerged in prepared suspension in membrane reservoir with a volume of 14 L. A cross-flow stream was produced by air bubbling generated by a diffuser situated underneath the submerged membrane module for mechanical cleaning of the membrane module. The air bubbling flow rates per unit projection membrane area was set constantly at 1.8 L/min in order to maintain proper turbulence. The filtration pressure was supplied by a vacuum pump and controlled by a needle valve at 0.5 bars. Permeate flow rates were continually recorded using a flow meter respectively.

The rejection test was carried out with distilled water and synthetic refinery wastewater with mixed liquor suspended solids (*MLSS*) concentration of 3-8 g/L. All experiments were conducted at 25$^o$C. Firstly, the pure water permeation flux ($J_w$) was measured using prepared PVDF submerged membrane under reduced pressure (0.5 bar) on the permeate side. Finally, the permeation measurement with refinery wastewater ($J_R$) and rejection ($R$) were measured under reduced pressure on the permeate side.

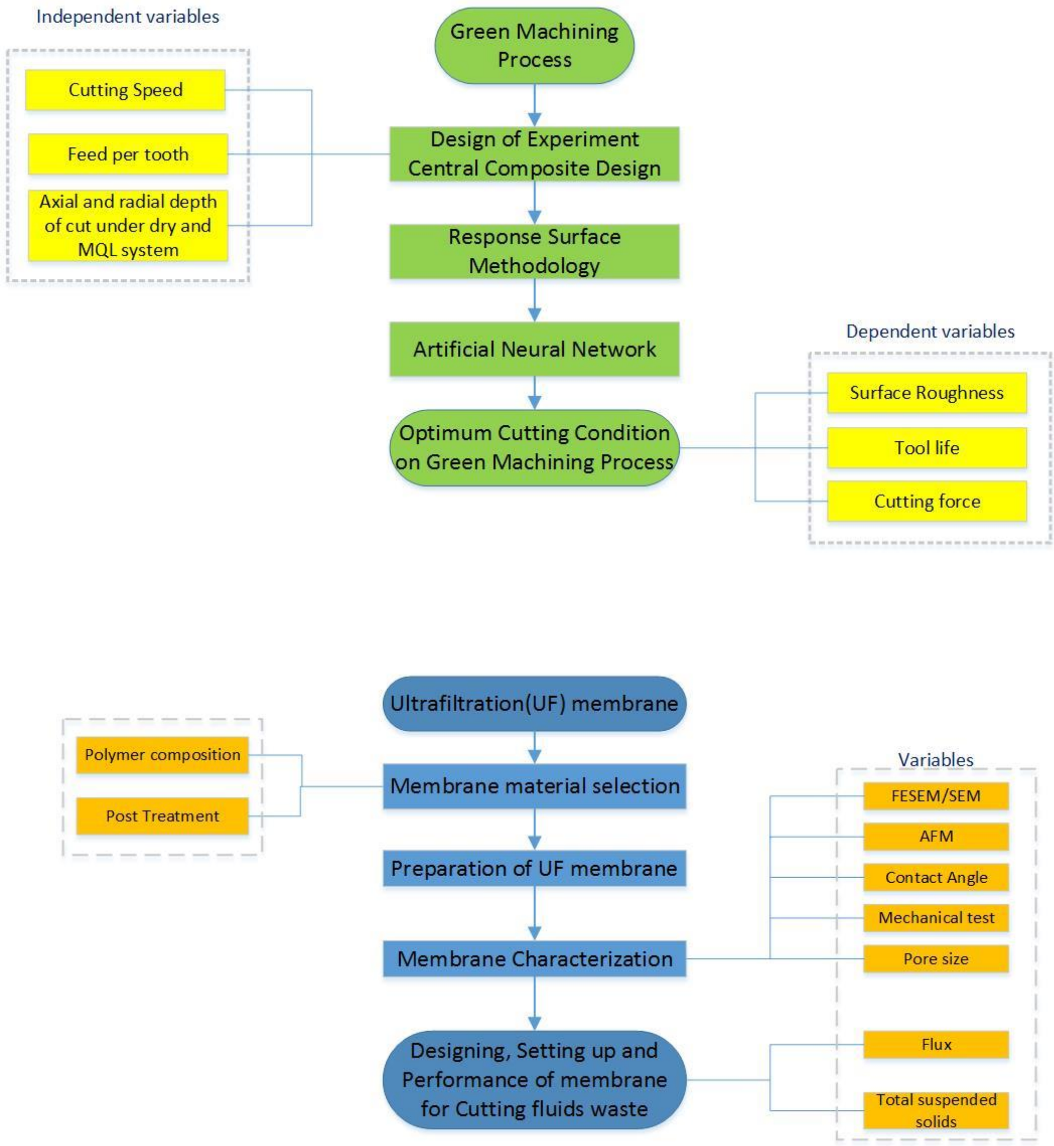


Figure 3.4 Schematic diagram of International Research Collaboration (IRC).

The Green machining process will be studied in the first and second year, while ultrafiltration membrane application will be run in the third year. In conjunction with this research the facilities of both Universities namely Sriwijaya Universities and Universiti Teknologi Malaysia, will be used simultaneously.

# CHAPTER 4
# EXPERIMENTAL RESULTS AND DISCUSSIONS

## 4.1 Program Management

This project covers a broad spectrum of disciplines and involves research from various mechanical engineering and chemical engineering background, including computational mechanics, construction and membrane technology application. An active research collaboration based on different background on the task - force team needs a proper preparation. Moreover, international publications and annual reports will be prepared on schedule by the person in charge. In addition, Calendar deliverable and milestones of this research are tabulated in Table 4.1.

Table 4.1 Research schedule.

| No. | Tasks | PIC | Team Members | Year 1 | | Year 2 | | Year 3 | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 6 | 12 | 6 | 12 | 6 | 12 |
| 01. | **Preparation**<br>-Meeting<br>-Local Seminar<br>-Roadshow/workshop | ASM | EY, SS, AFI, MY | The preparation is conducted during 2016, before project starting | | | | | |
| 02. | In-situ preparation | | | | | | | | |
| | -Materials sample | ASM | Team | | | | | | |
| | -Coolant sample | ASM | Team | | | | | | |
| 03. | Preliminary analysis | | | | | | | | |
| | -Determination of independent variables (screening tests) | ASM | EY, MY | | | | | | |
| | -Statistical design of experiment using RSM | ASM | EY, MY | | | | | | |
| | -Determination of dependent variables | ASM | EY, MY | | | | | | |
| | -Measuring the performance of dependent variables | ASM | MY | | | | | | |
| | -Submission first paper in International Conference | ASM | Team | | | | | | |
| 04. | An experimental process | | | | | | | | |
| | -Materials purchasing and preparation | ASM | SS, MY | | | | | | |
| | -Material dimensioning | ASM | MY | | | | | | |
| | -Purchasing of cutting tools | ASM | MY | | | | | | |
| | -Purchasing of coolant and MQL-system | ASM | MY | | | | | | |
| | -Machining process set up | ASM | MY | | | | | | |
| 05. | Data collecting and analysis | | | | | | | | |
| | -Analysis of workpiece microstructure | ASM | Team | | | | | | |
| | -Analysis of surface roughness and tool life. | ASM | Team | | | | | | |
| | -Analysis of SEM | ASM | Team | | | | | | |
| 06. | Finding optimum condition | | | | | | | | |
| | -Mathematical modelling RSM | ASM | Team | | | | | | |
| | -ANOVA Analysis | ASM | Team | | | | | | |
| | -Verification | ASM | Team | | | | | | |
| | -Submission second paper in International seminar | ASM | Team | | | | | | |
| | -Submission paper in International Journal | ASM | Team | | | | | | |
| | -Annual progress report | MY | Team | | | | | | |
| 07. | Data collecting and analysis | | | | | | | | |
| | -Analysis of mathematical model results by ANN | ASM | Team | | | | | | |
| | -Verification | ASM | Team | | | | | | |

| No. | Tasks | PIC | Team Members | Year 1 | | Year 2 | | Year 3 | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 6 | 12 | 6 | 12 | 6 | 12 |
| 08. | Advanced analysis | | | | | | | | |
| | -Analysis of Mathematical modelling result by ANN | ASM | Team | | | | | | |
| | -Submission second paper in International seminar | ASM | Team | | | | | | |
| | -Submission second paper in International Journal | ASM | Team | | | | | | |
| | -Annual progress report | MY | Team | | | | | | |
| 09. | Coolant disposal system | | | | | | | | |
| | -Identifying wasted coolant composition | ASM | SS, AFI, MY | | | | | | |
| | -Preparing of synthetic wasted coolant | EY | | | | | | | |
| 10. | Preparation of membrane system | | | | | | | | |
| | -Preparing membrane ultrafiltration for waste coolant disposal | EY | Team | | | | | | |
| | -Membrane structural analysis | EY | Team | | | | | | |
| | -Preparing and testing membrane system | EY | Team | | | | | | |
| | -Collecting data and analysis | EY | Team | | | | | | |
| | -Annual progress report | MY | Team | | | | | | |
| 11. | Final report and publications | | | | | | | | |
| | Submission third paper in International seminar | EY | Team | | | | | | |
| | -Submission second paper in International Journal | EY | Team | | | | | | |
| | -Final Report | MY | Team | | | | | | |

Note: ASM (Amrifan Saladin Mohruni), EY (Erna Yuliwati), SS (Safian Sharif), AFI (Ahmad Fauzi Ismail), MY (Muhammad Yanis/Engineer).

## 4.2 Proposed Budget

The proposed budget, which will cover all expenses for 3-years research duration, is shown in Table 4.2. The summary of the proposed research budget is shown in Table 4.3.

Table 4.2 Proposed research budget for three fiscal years.

| **No.** | **Fiscal Year** | **Proposed Research Budget** |
|---|---|---|
| 01. | 2016 | IDR 200.000.000,- |
| 02. | 2017 | IDR 200.000.000,- |
| 03. | 2018 | IDR 200.000.000,- |
| | **TOTAL=** | IDR 600.000.000,- |

Table 4.3 Summary of Research Budget

| No. | Item Costs | Proposed Costs (IDR). | | |
|---|---|---|---|---|
| | | 1st Year | 2nd Year | 3rd Year |
| 01. | Materials | 50.000.000,- | 40.000.000,- | 20.000.000,- |
| 02. | Equipment | 70.000.000,- | 60.000.000,- | 80.000.000,- |
| 03. | Transportations and Accommodations | 50.000.000,- | 50.000.000,- | 35.000.000,- |
| 04. | Data analysis, Final Report, Publications (International Conference), | 30.000.000,- | 30.000.000,- | 30.000.000,- |

| No. | Item Costs | Proposed Costs (IDR). | | |
|---|---|---|---|---|
| | | 1st Year | 2nd Year | 3rd Year |
| | Annual Costs = | 200.000.000,- | 200.000.000,- | 200.000.000,- |
| | Total Costs = | 600.000.000,- | | |
| (Six hundred million rupiahs) | | | | |

### 4.3 Results in Green Machining

Machining process in this research is conducted in collaboration with Production Laboratory of Universiti Teknologi Malaysia. Under this project worked 2 Ph.D. students, 3 postgraduate students and more than 10 undergraduate students.

At this time one PhD student has accomplished his seminar for research proposal and recently still conducting the experiment at Universiti Teknologi Malaysia. Another PhD student will present his research proposal on 17th December 2016. Two postgraduate students will present his final presentation on 10th December 2016. This research involved almost 10 undergraduate students and some of them have accomplished their study in machining on Ti-64.

### 4.4 Results in Environmental Friendly Coolant.

Due to the experiment in green machining is still ongoing at Production Laboratory of Universiti Teknologi Malaysia, the result in this field is to publish the literature review in 3rd International Conference on Green Design and Manufacture 2017, Krabi, Thailand. All accepted papers will be published in AIP Conference Proceeding indexed by scopus.

# CHAPTER 5
# CONCLUSIONS AND FUTURE WORKS

## 5.1 Conclusion

This chapter shows how the most relevant aspects of the developed work presented in this report can contribute to the state-of-the-art of the analysis for environmental friendly machining, which is a must in the future of the industries.

The optimum cutting condition will be established for the green machining and can be approved as reference in solving the recent environmental problem.

## 5.2 Future Works

The next step after all data which is planned to be complete collected at the middle of December 2016, is to start published papers of the research in International Journal indexed by Scopus and continuing the research for the cutting fluid performance after used in machining process.

# References


Alauddin, M., 1993. *End Milling Machinability Studies for Steel, a Nickel-base Alloy (Inconel718) and a Metal Matrix Composite.* Dublin(Dublin): Dublin City University, School of Mechanical and Manufacturing Engineering.

Alauddin, M., El Baradie, M. A. & Hashmi, M. S. J., 1996b. Modelling of Cutting Force in End Milling Inconel 718. *Journal of Materials Processing Technology,* 58(1), pp. 100-108.

Alauddin, M., El Baradie, M. A. & Hasmi, M. S. J., 1996a. Optimization of Surface Finish in End Milling Inconel 718. *Journal of Materials Processing Technology,* 56(1), pp. 54-65.

Alauddin, M. & El-Baradie, M. A., 1996. End-Milling Machinability of Inconel 718. *Proceeding of the Institutions of Mechanical Engineers, Part B: Journal of Engineering Manufacture,* 210(1), pp. 11-23.

Alauddin, M. & El-Baradie, M. A., 1997. Tool Life Model for End Milling Steel (190 BHN). *Journal of Materials Processing Technology,* 68(1), pp. 50-59.

Arrazola, P. J. et al., 2009. Machinability of titanium alloys (Ti6Al4V and Ti555.3). *Journal of Materials Processing Technology,* 209(5), pp. 2223-2230.

Balakrishan, P. & De Vires, M. F., 1983. *Analysis of Mathematical Model Building Techniques Adaptable to Machinability Data Base Systems.* Wisconsin, University of Wisconsin-Madison, Madison, Wisconsin, pp. 466-474.

Balakrishan, P. & De Vires, M. F., 1985. Sequential Estimation of Machinability Parameters for Adaptive Optimization of Machinability Data Base. *ASME, Journal of Engineering and Industry,* 107(2), pp. 159-166.

Belluco, W. & De Chiffre, L., 2001. Testing of Vegetable-Based Cutting Fluids in Hole Making Operations. *Lubrication Engineering,* Volume 57, pp. 12-16.

Box, G. E. P., Hunter, W. G. & Hunter, J. S., 1978. *Statistics for Experimenters.* 1st ed. New York: John wiley & Sons.

Box, G. E. P. & Wilson, K. B., 1951. On the Experimental Attainment of Optimum Conditions. *Journal of the Royal Statistical Society,* B(13), pp. 1-15.

Calamaz, M. et al., 2009. Toward a better understanding of tool wear effect through a comparison between experiments and SPH numerical modelling of machining hard materials. *International Journal of Refractory Metals and Hard Materials,* 27(3), pp. 595-604.

Choudhury, I. A. & El Baradie, M. A., 1998. Tool life Prediction Model by Design of Experiments for Turning High Strength Steel (290 BHN). *Journal of Materials and Processing Technology,* 77(1-3), pp. 319-326.

Choudhury, I. A. & El-Baradie, M. A., 1999. Machinability Assessment of Inconel 718 by Factorial Design of Experiment Coupled with Response Surface Methodology. *Journal of Materials Processing Technology,* 95(1-3), pp. 30-39.

Corduan, N. et al., 2003. Wear Mechanisms of New Tool Materials for Ti-6AI-4V High Performance Machining. *CIRP Annals - Manufacturing Technology,* 52(1), pp. 73-76.

El-Morsy, A. W., 2009. Microstructural characterization of Ti–6Al–4V machining chips after remelting and severe deformation. *Materials and Design 30 (2009) 1825–1829,* Volume 30, pp. 1825-1829.

Elshwain, A., Redzuan, N. & Yusof, N. M., 2013. MACHINABILITY OF NICKEL AND TITANIUM ALLOYS UNDER OF GAS-BASED COOLANT-LUBRICANTS (CLS) – A REVIEW. *IJRET: International Journal of Research in Engineering and Technology,* 2(11), pp. 690-702.

Galil, N. I. & Levinsky, Y., 2007. Sustainable reclamation and reuse of industrial wastewater including membrane bioreactor technologies: case studies. *Desalination,* Volume 202, p. 411–417.

Hammer, M. J. & Hammer Jr, M. J., 2008. *Water and Wastewater Technology.* 6th ed. s.l.:Mazon: Pearson Prentice Hall.

Ismail, A. F., Rahman, M. A., Mustafa, A. & Matsuura, T., 2008. The Effect of Processing Conditions on Polyacrylonitrile Fiber Produced Using Solvent-Free Coagulation Process. *Materials Science Engineering A,* Volume 485, pp. 251-257.

Jain, N. K., Jain, V. K. & Deb, K., 2007. Optimization of process parameters of mechanical type advanced machining processes using genetic algorithms. *International Journal of Machine Tools & Manufacture,* Volume 47, pp. 900-919.

Jiang, W., Childs, R. F., Mika, A. M. & Dickson, J. M., 2003. Pore-filled Membranes Capable of Selective Negative Rejections. *Nature and Science,* 1(1), pp. 21-26.

Judd, S., 2011. *The MBR Book, Principles and Applications of Membrane Bioreactors for Water and Wastewater Treatment.* 2nd Edition ed. UK: Butterworth-Heinemann.

Kalyandurg, I. B., 2003. *Study of Reaction Kinetics of a Submerged Membrane Activated Sludge Process,* DHAHRAN, SAUDI ARABIA: FACULTY OF THE COLLEGE OF GRADUATE STUDIES, KING FAHD UNIVERSITY OF PETROLEUM & MINERALS.

Kappmeyer, G. et al., 2012. Modern Machining of Advanced Aerospace Alloys - Enabler for Quality and Performance. *Procedia CIRP, 5th CIRP Conference on High Performance Cutting 2012,* 1(1), p. 28 – 43.

Koenig, W., 1979. Applied Research on the Machinability of Titanium and Its Alloys. *Proceeding 47th Meeting of AGARD Structural and Materials Panel, London,* Volume CP256, pp. 1-10..

Kuram, E., Ozcelik, B. & Demirbas, E., 2013. Environmentally Friendly Machining: Vegetable Based Cutting Fluids. In: J. P. Davim, ed. *Green Manufacturing Processes and Systems, Materials Forming, Machining and Tribology.* Berlin Heidelberg: Springer, pp. 23-47.

Lawal, S. A., Choudhury, I. A. & Nukman, Y., 2013. A critical assessment of lubrication techniques in machining processes: a case for minimum quantity lubrication using vegetable oil-based lubricant. *Journal of Cleaner Production,* Volume 41, pp. 210-221.

Lee, W., Kang, S. & Shin, H., 2003. Sludge characteristics and their contribution to microfiltration in submerged membrane bioreactors. *Journal of Membrane Science,* Volume 216, p. 217–227.

Lo, K. C. & Chen, N. N. S., 1977. Prediction of Tool Life in Hot Machining of Alloy Steels. *International Journal of Production Research,* 15(1), pp. 47-63.

Mansour, A. & Abdalla, A., 2002. Surface roughness model for end milling: a semi-free cutting carbon casehardening steel (EN32) in dry condition. *Journal of Materials Processing Technology,* 124(1-2), pp. 183-191.

Metcalf & Eddy, I., 2003. *Wastewater Engineering: Treatment and Reuse.* 3rd ed. Boston etc: McGraw-Hill International Editions.

Minnesota Technical Assistance Program (MTAP), 2015. *Developing a Coolant Maintenance Program for Machining Operations,* Minnesota: The University of Minnesota.

Mohruni, A. S., Sharif , S., Noordin, M. Y. & Venkatesh, V. C., 2007. *Application of Response Surface Methodology in the Development of Tool Life Prediction Models when End Milling Ti-6Al4V.* Jakarta, Indonesia, Proceeding of The 10th International Conference on Quality in Research (QIR), pp. IMM-20.

Montgomery, D. C., 2005. *Design and Analysis of Experiments.* 6th ed. New York, Chichester, Brisbane, Toronto, Singapore: John Wiley & Sons Inc.

Mulder, M., 1991. *Basic Principles of Membrane Technology.* ISBN 0-7923-0978-2 ed. Dordrecht: Kluwer.

Myers, R. H. & Montgomery, D. C., 2002. *Response Surface Methodology: Process and Product Optimization Using Designed Experiments.* 2nd ed. USA Canada: John Wiley & Sons, Inc.

Myers, R. H. et al., 2004. Response Surface Methodology: A Retrospective and Literature Survey. *Journal of Quality Technology,* 36(1), pp. 53-77.

Noordin, M. Y. et al., 2004. Application of Response Surface Methodology in Describing the Performance of Coated Carbide Tools when Turning AISI 1045 Steel. *Journal of Materials Processing Technology,* 145(1), pp. 46-58.

Paucksch, E., 1996. *Zerspantechnik 11. Auflage.* Wiesbaden (Germany): Vieweg Verlagsgesellschaft.

Pesek, S. C. & Koros, W. C., 1993. Aqueous quenched asymmetric polysulfone membranes prepared by dry/wet phase separation. *Journal of Membrane Science,* Volume 81, pp. 71-88.

Pinnau, I. & Koros, W. J., 1993. A qualitative skin layer formation mechanism for membranes made by dry/wet phase inversion.. *Journal of Polymer Science Part B: Polymer Physics,* 31(4), pp. 419-427.

Pulefou, T., Jegatheesan, V., Steicke, C. & Kim, S. H., 2008. Application of submerged membrane bioreactor for aquaculture effluent reuse. *Desalination,* Volume 221, p. 534–542.

Rautenbach, R. & Albrecht, R., 1989. *Membrane processes.* 1st ed. Chichester: John Wiley & Sons.

Ravanchi, M. T., Kaghazchi, T. & Kargari, A., 2009. Application of membrane separation processes in petrochemical industry: a review. *Desalination,* Volume 235, p. 199–244.

Raza, S. W., Pervaiz, S. & Deiab, I., 2014. Tool Wear Patterns When Turning of Titanium Alloy Using Sustainable Lubrication Strategies. *INTERNATIONAL JOURNAL OF PRECISION ENGINEERING AND MANUFACTURING,* 15(9), pp. 1979-1985.

Raza, S. W., Pervaiz, S. & Deiab, I., 2014. Tool Wear Patterns When Turning of Titanium Alloy Using Sustainable Lubrication Strategies. *International Journal of Precision Engineering and Manufacturing,* 15(9), pp. 1979-1985.

Reddy, N. S. K. & Rao, P. V., 2005a. A Genetic Algorithmic Approach for Optimization of Surface Roughness Prediction Model in Dry Milling. *Machining Science and Technology,* 9(1), pp. 63-84.

Reddy, N. S. K. & Rao, P. V., 2005b. Selection of Optimum Tool Geometry and Cutting Conditions using A Surface Roughness Prediction Model for End Milling. *The International Journal of Advanced Manufacturing Technology,* 26(11-12), pp. 1202-1210.

Reddy, N. S. K. & Rao, P. V., 2006. Selection of an optimal parametric combination for achieving a better surface finish in dry milling using genetic algorithms. *The International Journal of Advanced Manufacturing Technology,* 28(5), pp. 463-473.

Sahin, Y. & Motorcu, A. R., 2005. Surface Roughness Model for Machining Mild Steel with Coated Carbide Tool. *Material & Design,* 26(4), pp. 321-326.

Shashidhara, Y. M. & Jayaram, S. R., 2010. Vegetable Oils as a Potential Cutting Fluid—An Evolution. *Tribology International,* Volume 43, pp. 1073-1081.

Shaw, M. C., 2005. *Metal Cutting Principles (Oxford Series on Advanced Manufacturing).* New York Oxford: Oxford University Press; 2 edition.

Stephenson, D. A. & Agapiou, J. S., 1997. *Metal Cutting Theory and Practice 1st edition.* Michigan, USA: CRC Press.

The Central Statistics Agency of South Sumatra Province, 2015. *Sumatera Selatan dalam Angka.* 1st ed. Palembang: The Central Statistics Agency of South Sumatra Province.

Trent, E. M. & Wright, P. K., 2000. *Metal Cutting.* Boston Oxford Auckland Johannesburg Melbourne New Delhi: Butterworth Heinemann.

Wienk, I. M., Olde Scholtenhuis, F. H. A., Boomgaard, T. v. d. & Smolders, C. A., 1995. Spinning of hollow fiber ultrafiltration membranes from a polymer blend. *Journal of Membrane Science,* 106(3), pp. 233-243.

Wu, S. M., 1964. Tool Life Testing by Response Surface Methodology–Part 1 and 2. *ASME Transaction, Part B: Journal of Engineering for Industry,* 86(2), pp. 105-116.

Yoro Jr, A. U., 2010. Coco Oil as Cutting Fluid for General Machining. *Proceedings Education for sustainable development in Technical and Vocational Education and Training,* 3(2), pp. 291-297.

List of Publication

| | |
|---|---|
| (Mohruni, et al., 2016) | Mohruni, A.S., Yanis, M. and Kurniawan, E., 2016. Development of Surface Roughness Prediction Model for Hard Turning on AISI D2 Steel Using Cubic Boron Nitride ( CBN ) Insert. *Jurnal Teknologi (Sciences and Engineering)*, xxx(xxx), p.xxx. |
| (Suhaimi, et al., 2016) | Suhaimi, M.A., Hee, P., Sharif, S., Kim, D. and Mohruni, A.S., 2016. Cutting Force and Surface Roughness Characterization for High-Speed Milling of Compacted Graphite Iron. In *Sriwijaya International Conference on Engineering, Sicence and Technolgy (SICEST)*. pp. 1–6. |
| (Sharif, et al., 2016) | Sharif, S., Sadiq, I.O., Yusof, N.M. and Mohruni, A.S., 2016. Enhancement of Minimum Quantity Lubrication Technique by Nanofluids Application in Metal Cutting Operations : *MATEC Web of Conferences*, 4, pp.1–5. |
| (Tanwyn, et al., 2016) | Tanwyn, M., Khushairi, M., Sharif, S., Jamaludin, K.R. and Mohruni, A.S., 2016. Properties of Metal Filled Epoxy for Injection Mould Inserts. *International Journal on Advanced Science, Engineering and Information Technology (IJASEIT)*, pp.1–5. |
| (Mohruni, et al., 2017) | Mohruni, A.S., Yuliwati, E., Ismail, A.F. and Sharif, S., 2017. Membrane Technology for Treating of Waste Nanofluids Coolant: A Review. *AIP Conference Proceedings*, xxx(xxx), p.xxx. |

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Full Paper

# Development of Surface Roughness Prediction Model for Hard Turning on AISI D2 Steel using Cubic Boron Nitride Insert

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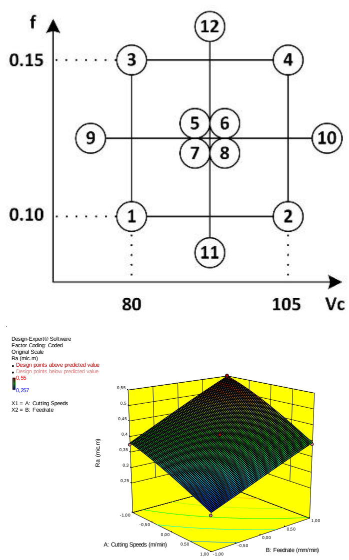
**Graphical abstract**




**Abstract**

Hard turning is an alternative to traditional grinding in the manufacturing industry for hardened ferrous alloy material above 45 HRC. Hard turning has advantages such as lower equipment cost, shorter setup time, fewer process steps, greater part geometry flexibility and elimination of cutting fluid. In this study, the effect of cutting speed and feed rate on surface roughness in the hard turning was experimentally investigated. AISI D2 steel workpiece (62 HRC) was machined with Cubic Boron Nitride (CBN) insert under dry machining. The $2^k$-factorial design with 4 centre points as an initial design of experiment (DOE) and the central composite design (CCD) as augmented design were used in developing the empirical mathematical models. They were employed for analysing of the significant machining parameters. The results show that the surface roughness value decreased (smoother) with increasing cutting speed. In contrary, surface roughness value increased significantly when the feed rate increased. Optimum cutting speed and feed rate condition in this experiment was 105 m/min and 0.10 mm/rev respectively with surface roughness value was 0.267 µm. Further investigation revealed that the second order model is a valid surface roughness model, while the linear model cannot be used as a predicted model due to its lack of fit significant.

*Keywords*: Hard turning, surface roughness, cutting speed, feed rate, dry machining, AISI D2-steel.



## 1.0 INTRODUCTION

Cutting of hardened steels is a topic of great interest in recent industrial production and scientific research. They are widely used in the automotive, gear, bearing, tool, and die industry. Traditionally hardened steels have been machined by the grinding process [1]. Hard turning is an alternative to traditional grinding in the manufacturing industry for hardened ferrous alloy material above 45 HRC [2]. It is a developing technology that offers many potential benefits compared to grinding, which remains the standard finishing process for critical hardened steel surface [3].

The advantages of hard turning are lower equipment cost, shorter setup time, fewer process steps, and greater part geometry flexibility. It is generally performed without a cutting fluid. Many studies have been conducted to investigate the performances of various grade cutting tools and various materials in hard turning. Cubic Boron Nitride (CBN) tools are widely used in the metalworking industry for cutting various hard materials such as high-speed tool steels, case-hardened steel, white cast iron, and alloy cast iron [4] [5].

Numerous previous studies were conducted using CBN tools on hardened ferrous alloy materials. Some of them investigated AISI D2 material using coated carbide tool, Pollycristalline Cubic Boron Nitride (PCBN) tool and ceramic tool because of its inertness with ferrous materials and high hardness. They evaluated the effect of cutting conditions on tool wear, surface roughness, power and cutting force [6] [7] [8] [9] [10] [11].

Until now studies in this field offered a lack of optimum empirical data which were experimentally investigated. Therefore the aim of this study is to fulfil and to analyse the lack of existing optimum data. In this study, the $2^k$-factorial design with 4 centres and the central composite design (CCD) were used as a design of experiment (DOE). The developed empirical mathematical models were generated using response surface methodology (RSM). The results was employed for analysing of the significantly influencing parameters.

## 2.0 METHODOLOGY

### 2.1 Mathematical Modelling

For developing empirical mathematical models it is necessary to build an initial mathematical surface roughness model as figured out in Equation 1. The relationship between surface roughness ($R_a$) with cutting speed ($V_c$) and feed rate ($f$) can be represented as follows:

$$R_a = CV^k f^l \quad (1)$$

where C is a constant of surface roughness, k and l are exponents of cutting speed and feed rate. To facilitate the determination of constants and exponents Equation 1 will have to be linearized by performing a logarithmic transformation as follows:

$$\ln R_a = \ln C + k \ln V + l \ln f \quad (2)$$

The linear model of Equation 2 is:

$$y = \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 \quad (3)$$

where $y$ is the true response of surface roughness on a logarithmic scale, $x_0$ = 1 (dummy variable), $x_1$ and $x_2$ are the logarithmic transformation of cutting speed and feed rate, while $\beta_0$, $\beta_1$, $\beta_2$, are parameters to be estimated in Equation 3 and can also be written as:

$$\hat{y}_1 = y - \varepsilon = b_0 x_0 + b_1 x_1 + b_2 x_2 \quad (4)$$

and the general second order polynomial response is given below:

$$\hat{y}_2 = y - \varepsilon = b_0 x_0 + b_1 x_1 + b_2 x_2 + b_{12} x_1 x_2 + b_{11} x_1^2 + b_{22} x_2^2 \quad (5)$$

where $\hat{y}_1$ and $\hat{y}_2$ is estimated response based on the first order and second order model equation as shown in Equation 1 and 5 respectively. The experimental error $\varepsilon$ and $b_i$ values are estimates of the $\beta i$ parameters. Adequacy of the selected model used for optimizing the process parameters has to be validated using analysis of variance (ANOVA).

### 2.2 Experimental Set-Up

The prepared AISI D2 steel with 62 HRC as shown in Figure 1 (a) was dry machined at a constant depth of cut (DOC) 0.5 mm in a CNC lathe Gildemeister CTX 310 ECO as shown in Figure 1 (b). The chemical composition of AISI D2 steel in average percentage is shown in Table 1.

**Table 1** Chemical composition of AISI D2 steel

| C | Si | Mn | Cr | Mo | V | Fe |
|---|---|---|---|---|---|---|
| 1.55 | 0.25 | 0.35 | 11.8 | 0.8 | 0.95 | Rest |

For this study, the CBN cutting inserts (S01030A TNGA 160 404 7025 SANDVIK) were installed in the tool holder 2020 DTJNR-16 K-type. The surface roughness measured, is the arithmetic mean deviation $R_a$. The measurements of surface roughness were carried out using a roughness gauge Accretech Handysurf E- 35A/E (speed 0.6 mm/s, evaluation length 12.5 mm and cut off 2.5 mm). The measurements of $R_a$ were taken three times for each sample and to obtain the average values.


(a) (b)

**Figure 1** (a). Prepared workpiece (b). CNC machine used in experiments

The development of the empirical mathematical model was started using $2^k$-factorial design. This factorial design is equipped with 4 centre points for estimating the pure error and the LoF (Lack of Fit) of the model as shown in Figure 2. After analysing of the $2^k$-factorial model, a further step is to augment the $2^k$-factorial design with the star points to produce a CCD. The CCD is one of the most important designs for fitting second order response surface models. This generated design consist of 12 experiments with 4 replicated centre points. The distance between centre point and star point is equal to $\alpha = \pm\sqrt{2}$ for rotatable design as shown in Figure 3. The rotatable design means that the variance of the predicted response at any point $n_x$ depends only on the distance of $\alpha$ from the design centre points. A design with this property can be rotated around its centre points without changing the prediction variance at $n_x$.

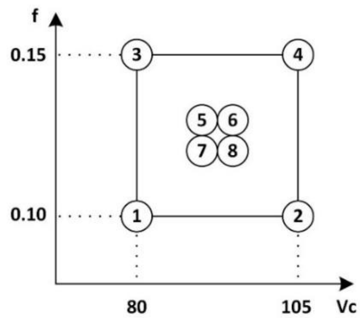



**Figure 2** The $2^k$-factorial initial design with 4 centre points

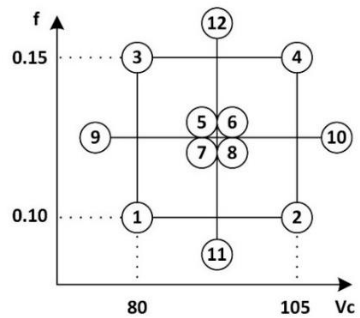



**Figure 3** The central composite design

The independent variables were coded by taking into account the capacity and limiting cutting conditions. The transforming equations for each variable are as below:

$$x = \frac{lnx_n - lnx_{no}}{lnx_{n1} - lnx_{no}} \quad (6)$$

where x is the coded value of any factor corresponding to its natural value $x_n$, $x_{n1}$, is the +*1* level and $x_{n0}$ is the natural value of the factor corresponding to the base of zero level [13][14]. The logarithmic transformation in Equation 6 was used for predicting the $R_a$ mathematical models in coded factor.

The levels of independent variables and the coded values are shown in Table 2. The observed surface roughness were captured by means of the optical microscope STM6-LM at 10 x magnification.

**Table 2** Levels of independent variables for AISI D2 steel

| Levels | Lowest | Low | Centre | High | Highest |
|---|---|---|---|---|---|
| Coding | -1.4142 | -1 | 0 | 1 | 1.4142 |
| Cutting speed, m/min | 74.82 | 80.00 | 92.50 | 105.00 | 110.18 |
| Feed rate, mm/rev | 0.09 | 0.10 | 0.13 | 0.15 | 0.16 |

## 3.0 RESULTS AND DISCUSSION

The trials were carried out according to Table 3. The analysis of this study was conducted using Design Expert 10.0 from Statease.

**Table 3** Cutting conditions and experimental results

| Standard | Cutting Conditions | | Surface Roughness |
|---|---|---|---|
| | $V_c$ m/min | f mm/rev | μm |
| 1 | 80.00 | 0.10 | 0.375 |
| 2 | 105.00 | 0.10 | 0.257 |
| 3 | 80.00 | 0.15 | 0.550 |
| 4 | 105.00 | 0.15 | 0.390 |
| 5 | 92.50 | 0.13 | 0.409 |
| 6 | 92.50 | 0.13 | 0.417 |
| 7 | 92.50 | 0.13 | 0.400 |
| 8 | 92.50 | 0.13 | 0.413 |
| 9 | 74.82 | 0.13 | 0.487 |
| 10 | 110.18 | 0.13 | 0.307 |
| 11 | 92.50 | 0.09 | 0.310 |
| 12 | 92.50 | 0.16 | 0.515 |

The ANOVA results of the 2F1-model is shown in Table 4. This figured out that the model is significant, but the LoF is also significant. This implies that the model is not valid and cannot be used as the $R_a$ prediction model.

**Table 4** ANOVA of the 2F1 model without adjustment of curvature effect

**The following ANOVA is for a model that does not adjust for curvature.**
**This is the default model used for prediction and model plots.**
**ANOVA for selected factorial model**
**Analysis of variance table [Partial sum of squares - Type III]**

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob.> F | |
|---|---|---|---|---|---|---|
| Model | 0,29 | 2 | 0.15 | 54.84 | 0.0004 | significant |
| A-$V_c$ | 0.13 | 1 | 0.13 | 49.21 | 0.0009 | |
| B-f | 0.16 | 1 | 0.16 | 60.48 | 0.0006 | |
| Residual | 0.013 | 5 | 2.646E-003 | | | |
| *Lack of Fit* | 0.012 | 2 | 6.138E-003 | 19.32 | 0.0193 | *significant* |
| *Pure Error* | 9.533E-004 | 3 | 3.178E-004 | | | |
| Cor. Total | 0.30 | 7 | | | | |

Further observation of this model is necessary to reveal if there are any evident of the curvature effect. This is the benefit of using centre points replicates, which gives the opportunity to confirm the presence of curvature effect.

This effect was observed in this model. The result is shown in Table 5. From this table, it is revealed that the curvature effect takes place in this 2F1 model. Therefore, it is indicated that a higher order model might be necessary to investigate in order to accurately represent the response.

**Table 5** ANOVA of the 2F1 model using adjustment of curvature effect

**The following ANOVA is for a model that does not adjust for curvature.**
**This is the default model used for prediction and model plots.**
**ANOVA for selected factorial model**
**Analysis of variance table [Partial sum of squares - Type III]**

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob.> F | |
|---|---|---|---|---|---|---|
| Model | 0.29 | 2 | 0.15 | 466.71 | < 0.0001 | significant |
| *A-V<sub></sub>*$_c$ | 0.13 | 1 | 0.13 | 418.72 | < 0.0001 | |
| *B-f* | 0.16 | 1 | 0.16 | 514.70 | < 0.0001 | |
| Curvature | 0.012 | 1 | 0.012 | 38.55 | 0.0034 | |
| Residual | 1.244E-003 | 4 | 3.109E-004 | | | |
| *Lack of Fit* | 2.903E-004 | 1 | 2.903E-004 | 0.91 | 0.4097 | *not significant* |
| *Pure Error* | 9.533E-004 | 3 | 3.178E-004 | | | |
| Cor. Total | 0.30 | 7 | | | | |

Further investigation is to utilize the higher order CCD in the finding of the valid empirical mathematical model for this study. Before the second order prediction model investigated it is useful to evaluate the first-order model for surface roughness in term of coded factors as initial observation, which is given by Equation 7.

$$\hat{y}_1 = -0.93 - 0.18x_1 + 0.20x_2 \qquad (7)$$

To conduct transforming of coded values to natural values, Equation 6 was used. The result of transformation is shown in Equation 8, which describes the relationship between surface roughness value to cutting speed and feed rate.

$$R_a = 1239.7987\, V^{-1.3239}\, f^{0.9865} \qquad (8)$$

The second-order surface roughness prediction model was described in Equation 9.

$$\hat{y}_2 = -0.89 - 0.17x_1 + 0.19x_2 - 0.00852x_1x_2 - 0.038x_1^2 - 0.022x_2^2 \qquad (9)$$

From Equation 9, it is revealed that increasing of cutting speed and feed rate contributed to 17% in decreasing of surface roughness value and to 19% in increasing of surface roughness value respectively. These results were also approved by Aouici *et al.* [5] and also Sahin and Motorcu [15].

The adequacy of Equation 9 was validated using ANOVA as shown in Table 6. From the results, it is to recognize that its LoF is not significant, which means that this equation is valid and can be used as a predicted surface roughness model.

**Table 6** ANOVA of the second order model using a CCD

**Response 1 Ra**
**Transform: Natural Log Constant: 0**
**ANOV A for Response Surface Quadratic model**
**Analysis of variance table [Partial sum of squares - Type III]**

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob.> F | |
|---|---|---|---|---|---|---|
| Model | 0,53 | 5 | 0,11 | 128,90 | < 0.0001 | significant |
| *A-V*$_c$ | *0,24* | *1* | *0,24* | *284,44* | *< 0.0001* | |
| *B-f* | *0,29* | *1* | *0,29* | *347,07* | *< 0.0001* | |
| *AB* | *2,903E-004* | *1* | *2,903E-004* | *0,35* | *0,5758* | |
| *A*$_2$ | *9,204E-003* | *1* | *9,204E-003* | *11,09* | *0,0158* | |
| *B*$_2$ | *2,963E-003* | *1* | *2,963E-003* | *3,57* | *0,1077* | |
| Residual | 4,979E-003 | 6 | 8,298E-004 | | | |
| *Lack of Fit* | *4,026E-003* | *3* | *1,342E-003* | *4,22* | *0,1338* | *not significant* |
| *Pure Error* | *9,533E-004* | *3* | *3,178E-004* | | | |
| Cor. Total | 0,54 | 11 | | | | |

The predicted surface roughness values were compared to the experimental results and is shown in Figure 4. It is obvious to recognize that both of them were almost matched on each trial. This curve proved also the ANOVA results.

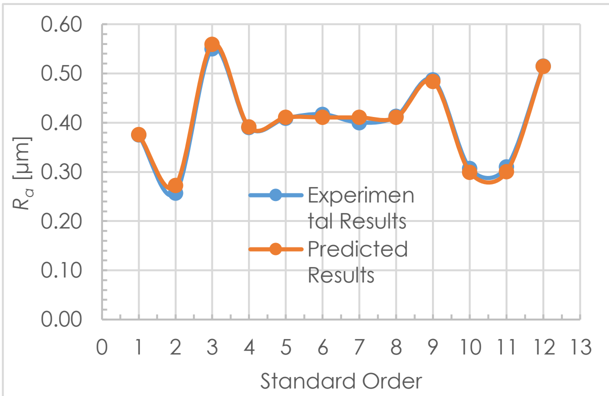



**Figure 4** Comparison between experimental and predicted surface roughness value $R_a$

The main effects and optimum cutting condition of machined surface are illustrated in Figure 5. The response surface shows that surface roughness value reduced (smoother) with increasing the cutting speed and the surface roughness value increased with increasing the feed rate. It is also figured out that the best surface roughness can be achieved when it run at cutting speed of 105 m/min and feed rate of 0.10 mm/rev. The optimum surface roughness value was 0.267 µm.

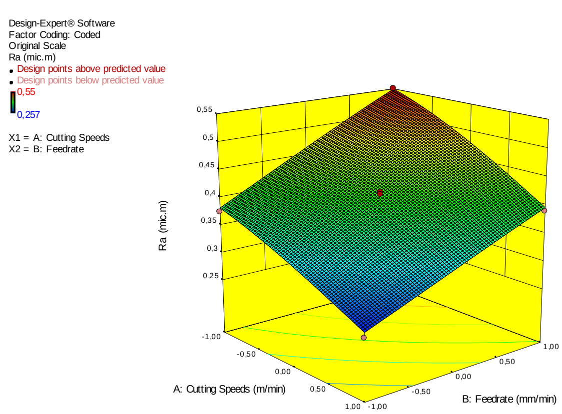
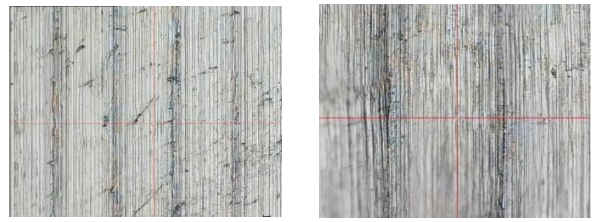



**Figure 5** The effect of cutting speed and feed rate on surface roughness

The patterns of tool path on machined surfaces are shown in Figure 6. They figured out the width of tool patterns according to feed rates. It is obvious to recognize that the higher the feed rate is, the wider is the tool pattern. It showed also increased feed rate affected on deeper resulted scratch on machined surfaces.



$V_c$ = 105 m/min, $f$ = 0,10 mm/rev

$V_c$ = 105 m/min, $f$ = 0,15 mm/rev

**Figure 6** The effect of cutting speed and feed rate on surface roughness (10x magnification)

This resulted pattern comply with the theory of metal cutting, which states that the surface roughness is proportional to the feed rate, while it is inversely proportional to cutting edge radius [16]. The surface quality generated by a simple external turning process is ignored the chip formation process, thus this case explores the generation of the kinematic surface roughness, as states in Equation 10.

$$R_t = r_\varepsilon - \sqrt{r_\varepsilon^2 - \frac{f^2}{4}} \ldots or \ldots R_t = \frac{f^2}{8.r_\varepsilon} \qquad (10)$$

where $R_t$ is the distance of the peak-to-valley in one groove, while $r\varepsilon$ is the radius of cutting edge.

On the other hand cutting speed contribution to the surface roughness can be explained as follows. Conventionally, the kinematic roughness is yielded by relative motion between workpiece and tool and by the edge radius. At low cutting speeds and certain material-tool combinations may lead to built-up edge (BUE) due to mechanical and thermal stresses. The material which builds up on the rake face is sporadically stripped off and transferred to the workpiece surface. With increased cutting speeds, this influence becomes increasingly insignificant. Thus the surface finish can be improved by increasing cutting speed, though the improvement was very limited.

In this case, the hardened steel was machined under cutting condition that higher than those favouring BUE formations. Indeed BUE didn't occur in this experiment. Therefore, the phenomenon needs further explanation.

According to Chen [17], it was shown the relationship between surface roughness and hardness of the material. It was found that the harder the workpiece, the lower the surface roughness obtained for a given set of machining parameters. Based on this finding, the lateral plastic flow of workpiece material along the cutting edge direction may increase the peak-to-valley height of surface irregularity. If the material presents less plasticity by increasing cutting speed implies that deformation velocity also increased. Therefore the surface finish can be improved as a result of less significant lateral plastic flow, thus less additional increase in the peak-to-valley height of the machined surface. It is evident that the properties of metals are influenced by the deformation velocity. The higher the velocity, the less significant the plastic behaviour will be.

In the SEM study by Chen [17], it was found that grooves developed on the flank wear land at low cutting speed. This was produced by cutting edge engagement with a workpiece. Furthermore, a part of the defects will be copied on the newly generated surface. In this condition, it is likely that the surface will be rough, thus to an increase in cutting speed the grooves will be gradually reduced. As the result, the cutting edge and wear land will become smoother, similarly the workpiece will also change to be in a less wavily form.

## Acknowledgment

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## 5.0 CONCLUSION

The investigation of surface roughness can be concluded as follows:

(a) Cutting speed and feed rate affected significantly on the quality of machined surfaces.
(b) Surface roughness value reduced (smoother) with increasing of the cutting speed. In contrary surface roughness value raised significantly with increasing the feed rate.
(c) The second order surface roughness predicted model is valid, while the linear model cannot be used due to its significant lack of fit.
(d) The optimum condition was obtained at cutting speed of 105 m/min and feed rate of 0.10 mm/rev for surface roughness value Ra equals to 0.267 µm.

## References

[1] Bouacha, K., Yallese, M. A., Khamel, S. & Belhadi, S. 2014. Analysis and Optimization of Hard Turning Operation Using Cubic Boron. *International Journal of Refractory Metals & Hard Materials.* 45: 160–178.

[2] Agrawal, A., Goel, S., Rashid, W. B. & Price, M. 2015. Prediction of Surface Roughness during Hard Turning of AISI 4340 Steel (69 HRC). *Applied Soft Computing,* 30: 279-286.

[3] Davim, J. P. 2011. *Machining of Hard Materials.* 1st Ed. Heidelberg Dordrecht, London, New York: Springer.

[4] Gaitonde, V. N., Karnik, S. R., Figueira, L. & Davim, J. P. 2009. Machinability Investigations in Hard Turning of AISI D2 Cold Work Tool Steel With Conventional and Wiper Ceramic Inserts. *International Journal of Refractory Metals & Hard Materials,* 27: 754-763.

[5] Aouici, H., Yallese, M. A., Chaoui, K., Mabrouki, T., Rigal, J. F. 2012. Analysis of Surface Roughness and Cutting Force Components in Hard Turning with CBN Tool. *Measurement,* 45: 344-353.

[6] Sahin, Y. 2009. Comparison of Tool Life Between Ceramic and Cubic Boron Nitride (CBN) Cutting Tools When Machining Hardened Steels. *Journal of Materials Processing Technology,* 209: 3478-3489.

[7] Yallese, M. A., Chaoui, K., Zeghib, N., Boulanouar, L., Rigal, J. F. 2009. Hard Machining of Hardened Bearing Steel Using Cubic Boron Nitride Tool. *Journal of Materials Processing Technology,* 209: 1092-1104.

[8] Hessainia, Z., Belbah, A., Yallese, M. A., Mabrouki, T., Rigal, J. F. 2013. On the Prediction of Surface Roughness in the Hard Turning Based on Cutting Parameters and Tool Vibrations. *Measurement,* 46: 1671-1681.

[9] Srithara, A., Palanikumar, K., Durgaprasad, B. 2014. Experimental Investigation and Surface roughness Analysis on Hard turning of AISI D2 Steel using Coated Carbide Insert. *Procedia Engineering 12th Global Congress on Manufacturing and Management (GCMM) 2014,* 97: 72-77.

[10] Arsecularatne, J. A., Zhang, L. C., Montross, C., Mathew, P. 2006. On Machining of Hardened AISI D2 Steel with PCBN Tools. *Journal of Materials Processing Technology,* 171: 244-252.

[11] Ozel, T., Karpat, Y., Figueira, L., Davim, J. P. 2007. Modelling of surface finish and tool flank wear in turning of AISI D2 steel with ceramic wiper inserts. *Journal of Materials Processing Technology,* 189: 192-198.

[12] Sharif, S., Mohruni, A. S., Noordin, M. Y., Venkatesh, V. C. 2006. Optimization of Surface Roughness Prediction Model in End Milling Titanium Alloy (Ti-6Al4V). *International Conference on Manufacturing Science and Technology (ICOMAST 2006),* Malacca, Malaysia. 28-30 August, 55-58.

[13] Reddy, N. S. K., Rao, P. V. 2005. Selection of Optimum Tool Geometry and Cutting Conditions using A Surface Roughness Prediction Model for End Milling. *The International Journal of Advanced Manufacturing Technology,* 26(11-12): 1202-1210.

[14] Ginta, T. L., Nurul Amin, A. K. M., Mohd Radzi, H. C. D., Lajis, M. A. 2009. Tool Life Prediction by Response Surface Methodology in End Milling Titanium Alloy Ti-6Al-4V Using Uncoated WC-Co Inserts. *European Journal of Scientific Research,* 28(4): 533-541.

[15] Sahin, Y., Motorcu, A. R. 2008. Surface Roughness Model in Machining Hardened Steel with Cubic Boron Nitride Cutting Tool. *International Journal of Refractory Metals & Hard Materials,* 26: 84-90.

[16] Klocke, F. 2011. *Manufacturing Processes 1: Cutting (RWTH edition) translated by Aaron Kuchle.* 1st Ed. Berlin, Heidelberg: Springer Verlag.

[17] Chen, W. 2000. Cutting Forces And Surface Finish when Machining Medium Hardness Steel Using CBN Tools. *International Journal of Machine Tools & Manufacture,* 40: 455-466.

# Cutting Force and Surface Roughness Characterization for High-Speed Milling of Compacted Graphite Iron

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**Abstract:** Compacted Graphite Iron, (CGI) is among one of the cast iron which has outstanding mechanical strength and weight-to-strength ratio as compared to conventional grey cast iron, (CI). The outstanding characteristics of CGI is due to its graphite particle shape, which is presented as compacted vermicular particle. The graphite is interconnected with random orientation and round edges, which results in higher mechanical strength. Whereas, graphite in the CI consists of a smooth-surfaced flakes that easily propagates cracks hence results in weaker and brittle properties as compared to CGI. Owing to the improved properties, CGI is considered as the best candidate material in substituting grey cast iron that has been used in engine block applications for years. However, the implementation is still limited due to the poor machinability of CGI especially at high cutting speed. The tool life is decreased by 20 times when comparing CGI with CI under the same cutting condition. This study investigates the effect of using cryogenic cooling and minimum quantity lubrication (MQL) during high-speed machining of CGI (grade 450). Results showed that, the combination of internal cryogenic cooling and enhanced MQL improved the tool life, cutting force and produce better surface quality as compared to the conventional flood coolant strategy.

**Keywords:** Compacted Graphite Iron; Cryogenic cooling; Tool wear; Minimum Quantity Lubrication

## 1. INTRODUCTION

Grey Cast Iron (CI) has been widely used in the manufacturing of engine blocks and cylinder heads for so many years due to its mechanical and physical properties. However, the repetition of start-up and shut-down of engines can cause high mechanical loading and may lead to localized crack at the engine blocks and heads as a result of thermo-mechanical fatigue [1, 2]. From this aspect, researchers have found that Compacted Graphite Iron (CGI) is the best candidate in replacing CI. The graphite structure of CGI is interconnected with random orientation and round edges exhibits better mechanical strength than that of CI. Whereas graphite in the CI presents smooth surface flakes that easily propagates cracks resulting in weaker and brittle properties when compared to CGI as shown in Fig. 1. Table 1 shows the mechanical and physical properties of CGI in comparison to CI [3]. The tensile strength and fatigue strength of CGI are almost double than CI, the elastic modulus is 38% higher than CI, and the thermal conductivity is 28% smaller than CI. Owing to the improved properties, CGI is considered a suitable candidate to substitute the grey cast iron in various components for diesel engine; such as engine blocks, cylinder heads and cylinder sleeves [4].

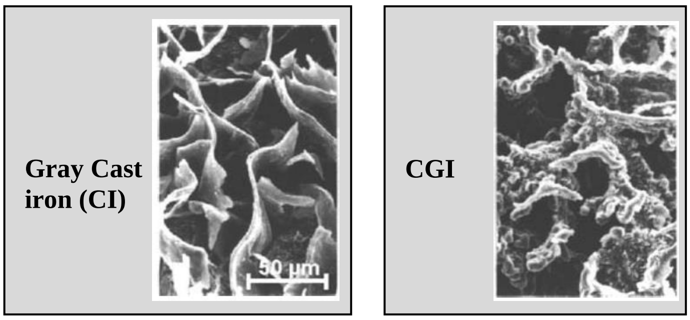



**Fig. 1: Graphite particle shape of gray iron and compacted graphite iron [5]**

Furthermore, the outstanding mechanical strength of CGI material enables the CGI-based engines to operate at higher temperature and cylinder pressure, which improved fuel consumptions, hence produce lower levels of emissions. In addition, CGI is lighter than CI as confirmed by Hyundai Motor Company whereby their CGI-based engine of 1.8L I-4 Diesel is 22 % lighter compared to the CI-based engine of the same kind [3].

**Table 1: Mechanical and physical properties of CGI (GJV) compared to conventional grey cast iron (GJL).**

| Properties | Units | GJV 450 | GJL 250 | GJL 300 |
|---|---|---|---|---|
| Ultimate tensile strength | MPa | 450 | 250 | 300 |
| Rotating-bending fatigue (20 ºC) | MPa | 210 | 110 | 125 |
| Rotating-bending fatigue (225 ºC) | MPa | 205 | 100 | 120 |
| Elastic modulus | GPa | 145 | 105 | 115 |
| Elongation | % | 1-2 | 0 | 0 |
| Thermal conductivity | W/m.K | 36 | 46 | 39 |
| Thermal expansion | µm/m.K | 12 | 12 | 12 |
| Density | g/cc (CGS system) | 7.7 | 7.1 | 7.1 |
| Brinell hardness | BHN 10-3000 | 215-255 | 190-225 | 215-255 |

Yang et al. [6] studied the remanufacturing capability of automotive products by considering four different materials, used as engine block, namely Grey Cast Iron (CI) ASTMA48 Class 40, Aluminum A356-t6, Magnesium AMC SC1 T6 and CGI ASTM A482 Grade 450. The remanufacturing performance was ranked based on material's durability, clean-ability, restorability, environmental health and safety, material cost and material density. The authors found that CGI is more superior compared to CI in terms of remanufacturing performance. However, the poor machinability of CGI is the major barrier to the automotive industries in producing high performance engines with effective tool life, especially, when high-speed machining is applied to bore engine cylinders in an automated transfer line. According to Heck et al. [7], the tool life is decreased approximately by the factor of 20 when changing to CGI from CI for the same cutting condition. Whereas, Dawson et al. [8] reported that when machining CGI the tool life reduced to 10% as compared to CI for both turning and milling process using PCBN and carbide tools. Da Silva et al. [9], performed a tool life comparison between CGI and CI for high speed face milling. They found that, the flank wear was 100 % greater for CGI compared to CI at cutting speed of 600 m/min.

It is well known that, the decreased in tool life is due to the absence of Manganese-Sulfide (MnS) layer, which acts as a protective surface to avoid adhesion at the tool-chip interface in the case of machining CI [5, 10]. The most significant difference between CI and CGI is the sulfur content. CGI consists of almost 90% less sulfur content compared to CI. In machining CI, sulfur reacts with manganese to form MnS inclusions that forms a thin layer and acts as lubrication on the cutting edge surface. The MnS layer may also reduce the cutting temperature, hence decreases the oxidation and diffusion rates [10]. To demonstrate this effect, Dawson et al. [8] compared the tool life by using different cutting speeds for machining both CGI and CI. As cutting speed increased to 400 m/min, a built-up layer containing MnS began to form on the cutting edge and the thickness of the layer increased as the cutting speed was raised to 800 mm/min. In contrast, with the same cutting condition applied to CGI, the tool suffered from abrasive flank wear with increasing cutting speed. Bazdar et al. [11] attempted to increase the sulfur content on the graphite aspect ratio of a commercial CGI in order to improve the machinability. However, the tensile properties of the modified CGI decreased as compared to the commercial CGI.

The main purpose of this study is to investigate the effectiveness of various cooling/lubrication strategies in machining CGI. The performance of uncoated carbide tool was tested at three different cutting speeds (400, 600 and 800 m/min) and two feed rates (0.1 and 0.2 mm/tooth). The progression of tool wear based under various cooling/lubrication was recorded and analyzed. In order to evaluate the effectiveness of each different cooling/lubrication strategy, cutting force and surface roughness were measured at all conditions investigated. First, an experiment with conventional flood coolant (WET) was employed and the tool wear progression was used as the benchmark for other cooling/lubrication strategies, such as; Minimum Quantity Lubrication (MQL) with added nano-particles (nMQL), nano-MQL with combination of external cryogenic cooling (nMQL + ExtCryo), and nano-MQL with combination of internal cryogenic cooling (nMQL + IntCryo). Then, the respective cutting forces were acquired in real-time and surface roughness were measured at the end of each experiment. Finally, the tool wear was measured using a confocal laser microscope. The worn tools were analyzed under a Scanning Electron Microscope (SEM) and Energy Dispersive X-ray to examine the predominant type of wear mechanisms and chemical characterization, respectively.

## 2. RESEARCH BACKGROUND

Cooling and lubrication play an important role in metal cutting process for transferring excessive heat at the tool/workpiece engagement region and reducing tool wear. In addition, these applications are able to reduce the power consumption and at the same time improve the surface quality and productivity. In a conventional machining of most metals, a flood coolant system is preferable due to the effective cooling and ease of the application. However, flood coolant is less effective when working with difficult-to-cut and low thermal conductivity materials such as CGI. To deal with extremely high cutting temperature when machining these materials, several studies has been conducted by employing cryogenic cooling with liquid nitrogen (LN2). It has been proved that cryogenic cooling results in a better tool-life [12, 13] and lower cutting force [14] when machining titanium alloys Due to the low temperatures below -180 ºC, liquid nitrogen has been used in a wide variety of application for cooling purposes. In addition, LN2 is odorless and more environmental friendly compared to the conventional flood coolant [15]. Nevertheless, reports on the performance of cryogenic cooling when machining of CGI are very limited. It was very common that an external spray nozzle is used to supply LN2 to the cutting tool as shown reported by many researchers since year 2001 until now [16-20]. By this way, the surface hardness of the workpiece material may increase due to the excessive LN2 spray. Fig. 2 shows the hardness of CGI Grade 450 with respect to testing temperature, and the effect of the excessive cryogenic cooling using conventional external spray. It is clearly showed that the hardness can be easily increased to 16%, due to the effect of excessive LN2 of the external cryogenic cooling. Similarly, Shokrani et al. [21] reported that the hardness of Ti-6Al-4V increases from 32HRc to 42HRc due to the exposure of LN2. Therefore, in order to solve the excessive spray effect, a specially designed tooling kit (as shown in Fig. 3) was used in this study which enables the supply of liquid nitrogen to the cutting tool internally. The performance of the newly designed tooling kit was evaluated accordingly..

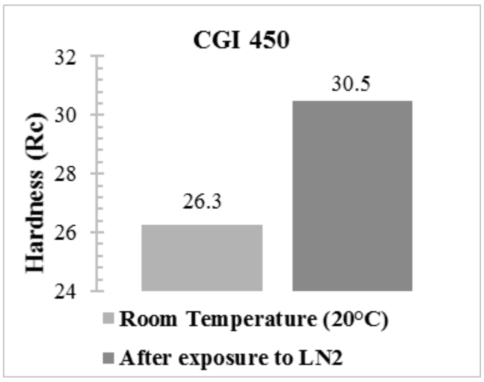



**Fig. 2: The effect of the excessive cryogenic due to the conventional external spray of CGI 450**

Minimum quantity lubrication (MQL) is well known for its capability for cooling and lubricate the cutting tool simultaneously. However, MQL is less effective under high-speed machining as the sprayed oil simply evaporates as soon as the spray contacted the high temperature tool. In this study, a nano-particle is added with the vegetable-based oil, similar to that study conducted by Park et al. [22]. It their study, it has been proved that, the enhanced exfoliated nano-graphene (xGnP) vegetable-based oil performed better in terms of reducing the tool wear of a ball-milling process compared to the traditional MQL vegetable oil. The added nano-particles provide additional lubrication to the cutting tool even when the MQL spray already evaporates. This is due to the nano-particles is arranged in a multiple-layer structure. With the same interest, Nguyen et al. [23] did a comparative study on the effectiveness of added nano-particle MQL by xGnP and Hexagonal Boron Nitride (hBN). They reported that, the mixture of hBN particles reduce the flank wear and central wear of a ball-milling process better than xGnP mixture.

This study investigated the effectiveness of MQL with added nano-particle using MQL with added hBN nano-particle when machining CGI. In addition, the combination of both external and internal spray of cryogenic cooling and enhanced nano-hBN lubricant was also performed.

## 3. EXPERIMENTAL METHODOLOGY

The experiments were performed on a three-axis vertical milling center, Mori Seiki NVD-4000-DCG-HSC with Fanuc CNC controller. The cutting tool used in the machining test was an indexable end-milling cutter with designated code R390-016A16L-11L with two cutting edges. The tool diameter was 16 mm. The insert used was uncoated carbide (grade H13A). from Sandvik-CoroMill 390 (Its helix angle was 21º and the corner radius was 0.8 mm.

The workpiece material is a commercially CGI (grade GJV 450) with size of 100 x 100 x 300-mm block from SinterCast. The mechanical and physical properties of the workpiece are shown in Table 1. Table 2 presents the chemical composition of the workpiece according to the material producer. The cutting parameters was defined according to the standard production line and also based on previous published work. The machining conditions are shown in Table 3.

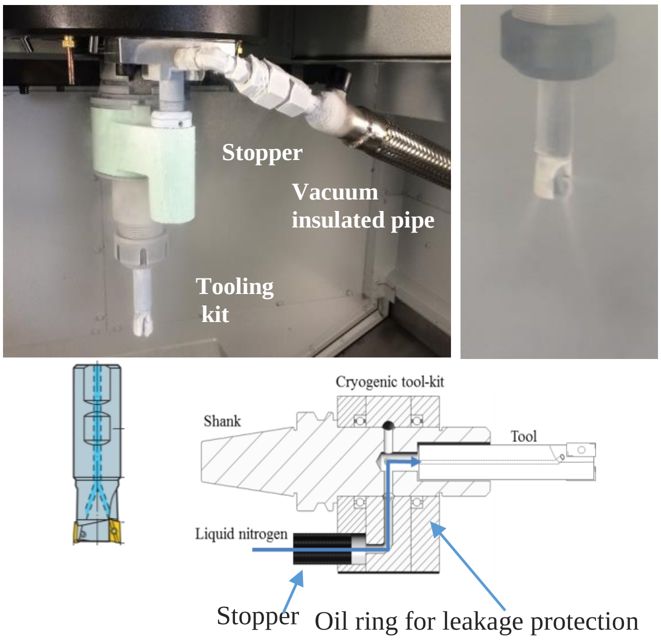



**Fig. 3: Custom designed of internal cryogenic cooling tooling kit.**

For each experiment, a 3D laser scanning microscope (CLSM), Model: Keyence VK-X200 with a magnification of 10x, has been used to capture the image of corresponding tool wear. Measuring software, known as 'VK Analyzer', has been used to measure the average flank and crater wear from the captured image. The worn tools were analyzed in a scanning electron microscope (SEM) and energy dispersive X-ray spectroscopy (EDX) in order to identify the predominant type of wear mechanisms and to measure the chemical weight percentage adhere on the tool.

Due to the irregular shape of the workpiece stock from the as-cast effect, a layer of approximately 2 mm was removed by face milling before the actual experiment starts. A total of 24 experiments were conducted which consists of different 6 combinations of cutting parameters for each cooling/lubrication method.

**Table 2: Chemical composition of CGI, GJV 450.**

| | wt. % |
|---|---|
| **C** | 3.55 |
| **Si** | 2.25 |
| **Mn** | 0.40 |
| **S** | 0.0065 |
| **Cr** | 0.029 |
| **Cu** | 0.81 |
| **Mg** | 0.009 |
| **Sn** | 0.075 |
| **Ti** | 0.009 |

**Table 3: Machining conditions**

| Condition | Description |
|---|---|
| Cutting speed, Vc | 400, 600 & 800 m/min |
| Feed per tooth, fz | 0.1 & 0.2 mm |
| Axial depth of cut | 2 mm |
| Radial depth of cut | 5 mm |
| Cutting length | 375 mm |

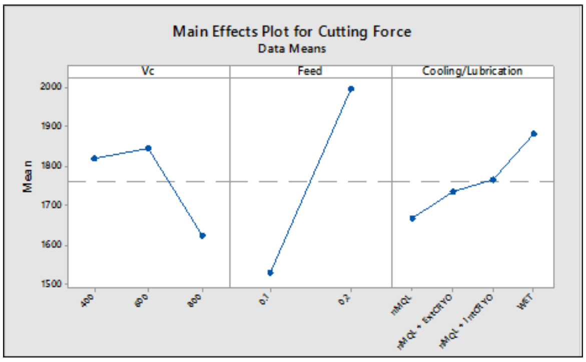
## 4. RESULTS AND DISCUSSION

Fig. 4 presents the main effects of cutting force, surface roughness and average flank wear with respect to different cutting speed (Vc), feed-per-tooth (fz) and cooling/lubrication methods. Results show that, there is no significant effect on the cutting force for the change of Vc from 400 to 600 m/min. But, cutting force is decreased as Vc increased to 800 m/min, similar to the findings by Oxley [24], cutting force decreased as the cutting speed increases until at certain point before increase back due to material's strain characteristics. However, cutting force increased significantly with increased in feed rate (fz), due to the double increment of material removal rate from 7.95 $cm^3$/min to 15.91 $cm^3$/min. Meanwhile, WET consumed the highest cutting force compared to other cooling and lubrication methods. This is due to the inefficient cooling of the conventional flood coolant method. For that reason, WET strategy appears to suffer from the worst tool life as shown in Fig. 4(c). Fig. 5 reveals the EDX analysis of the tool flank face under WET strategy. Due to inefficient cooling, the EDX spectra reveals that, the tool material for WET strategy presents a strong adhesion of workpiece material. A highest concentration of iron, carbon, silicon, manganese and copper under all cutting conditions using WET strategy as cooling/lubrication method. These chemical elements are the main element of the workpiece material. As an example, for Vc = 800 m/min and fz = 0.2 mm (Fig. 5), the weight percentage of iron for WET are 86% followed by 84%, 78% and 76% for NanoMQL, NanoMQL+ExtCryo and NanoMQL+IntCryo, respectively. Perhaps, the cutting tool from WET strategy suffers thermal cracks at the tool cutting edge. These cracks are caused by cycling variation of temperature and frequently happen perpendicular to the cutting edge. The thermal cracks damage only appears after machining at cutting speed of 600 and 800 m/min under WET strategy as reported by Silva et al. [9]. Severe cracks may cause frittering hence causing poor surface finish and excessive flank wear as shown in Fig. 6.

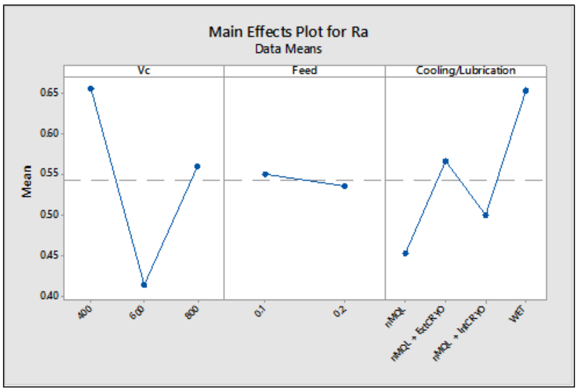
The results for surface roughness (Fig. 4 (b)) for the whole set of experiments were fund to be below 1.0 micron, which is within the acceptable range for rough milling process. The main effects diagram showed that at Vc = 600 m/min, the finest quality was recorded below the average surface quality for both MQL and MQL + Internal Cryogenic cooling, compared to MQL + ExtCryo cooling and WET which produced the worst surface roughness value. There was no significant effect on surface roughness for the change of feed, fz.

The main effect for average flank wear (Fig. 4 (c)) reveals that flank wear is at smallest amount when cutting speed was at 600 m/min. The average flank wear is improved when higher feed was applied. More importantly is the effects of cooling/lubrication methods. The results show that WET, Nano-MQL and NanoMQL+ExtCryo has the worst tool life compared to NanoMQL+IntCryo. As mentioned before, under WET condition, the tool suffered from thermal cracks and excessive adhesion of workpiece material. As for Nano-MQL, the tool flank wear recorded the worst roughness value due to inability of MQL to penetrate outside the region of slipping, between the primary and secondary zone. This also may be due to effect of higher cutting speed and higher feed employed.

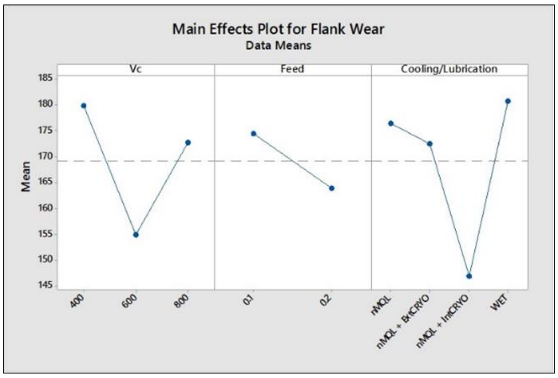
As shown in Table 4, the burn mark increased as cutting speed increased for both feed rates under MQL strategy. For NanoMQL+Ext Cryo, even though cryogenic cooling promises an excellent cooling capability, however due to the excessive amount of liquid nitrogen being exposed to the workpiece, it causes the hardness of the workpiece to increase, similar to the study reported by Park et al. [25]. It was evident that cryogenic cooling using the proposed tooling kit devise is able to control the cryogenic spray from spreading to the workpiece hence increases the hardness. As a results, NanoMQL+IntCryo was found to outperform other cooling/lubrication methods in improving the tool life.




a) Cutting force




b) Surface roughness




c) Average flank wear

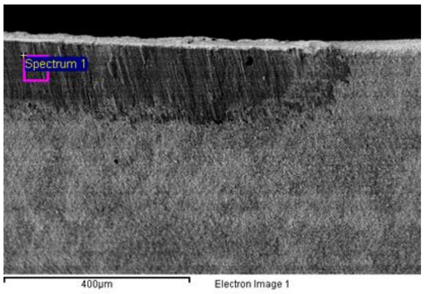
**Fig. 4 Main effects of cutting force, surface roughness and average flank wear**

**Table 4: Tool flank face captured for average flank wear measurements**

| Cutting Condition Vc | Cutting Condition Fz | Coolant/lubrication Methods: Nano-MQL | Coolant/lubrication Methods: Nano-MQL+IntCryo |
|---|---|---|---|
| 400 | 0.1 |  |  |
| 600 | 0.1 |  |  |
| 800 | 0.1 |  |  |
| 400 | 0.2 |  |  |
| 600 | 0.2 |  |  |
| 800 | 0.2 |  |  |

Since the main effect only shows the effect of one independent variable on the response variables by ignoring the effects of other independent variables, the potential of making error conclusion may occur. Hence, Fig. 7 shows the interaction effects for the cutting force and surface roughness. A statistical interaction occurs when the effect of one independent variable on the dependent variable changes depending on the level of another independent variable.

From Fig. 7, it can be concluded that, there is no interaction effect for all the main effects for cutting force (Fig. 7 (a)). As for the surface roughness (Fig. 7 (b)), there is no interaction effect except for Vc and fz. Instead, a cross over interaction effect was observed for Vc and fz on surface roughness, which implies both variables have no influence on surface roughness. So, the variation of surface quality is solely dependent on the application of cooling/ lubrication methods.



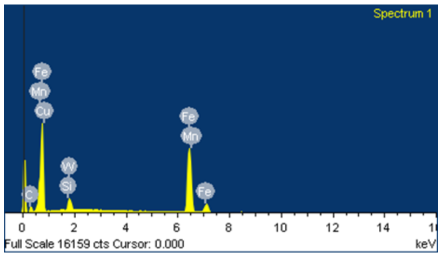




**Fig. 5: EDX at the flank face after machining CGI at Vc = 800 m/min and fz = 0.2 mm with WET strategy**

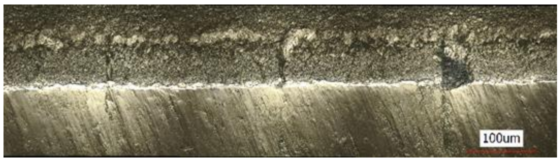
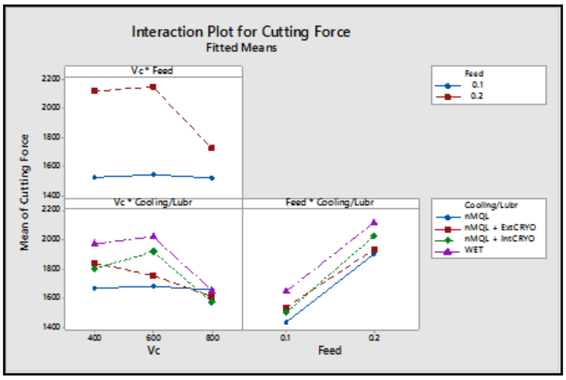
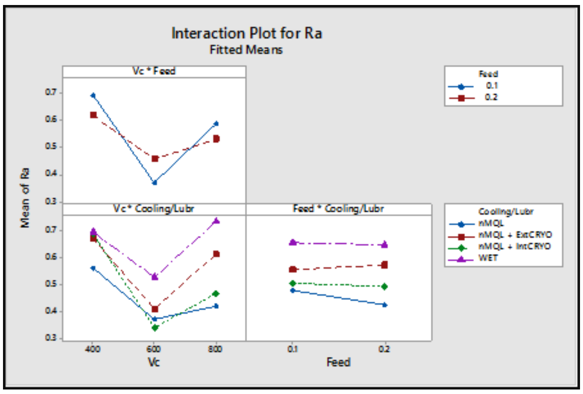



**Fig. 6: Tool cutting edge for WET strategy for cutting coondition of Vc = 600 m/min and fz = 0.2 mm**




a) Cutting force




b) Surface roughness

**Fig. 7 Interaction effects of cutting force and surface roughness**

Results indicated that MQL and MQL + Internal Cryogenic cooling were able to produce the best surface quality while WET and external cryogenic cooling produced the worst surface quality. From the overall performance it can be concluded that, increase in cutting speed and feed do not affect the surface roughness, due to the acceptable range of surface roughness reading obtained for all cooling/lubrication methods which is below than 1.0 micron.

## 5. CONCLUSIONS

From the investigation conducted, it can be suggested that:

i. Cutting force is inversely proportional to the cutting speed. In addition, cutting force increased significantly when higher feed is employed.

ii. NanoMQL has the worst tool life even though consumed lowest cutting force. This effect was due to thermal softening of the tool and workpiece. The combination of heat and shear stress at the primary and secondary zones resulted in high temperature and stress generation at the cutting zone.

iii. The proposed tooling kit devise was able to efficiently transfer the cryogen to the cutting zone and effectively cool the tool without increasing the workpiece hardness. Hence, the tool life for Nano-MQL+Internal Cryogenic method outperformed other cooling/lubrication strategies.

iv. Cutting speed and feed per tooth do not influence the surface roughness. The surface roughness was significantly affected by the application of cooling and lubrication methods. However, all experiments present acceptable surface roughness values of below 1.0 micron.

## REFERENCES


[1] M. Riedler, H. Leitner, B. Prillhofer, G. Winter, and W. Eichlseder, "Lifetime simulation of thermo-mechanically loaded components," *Meccanica,* vol. 42, pp. 47-59, 2007.

[2] V. Norman, P. Skoglund, D. Leidermark, and J. Moverare, "Thermo-mechanical and superimposed high-cycle fatigue interactions in compacted graphite iron," *International Journal of Fatigue,* vol. 80, pp. 381-390, 2015.

[3] S. Dawson and F. Hang, "Compacted graphite iron-a material solution for modern diesel engine cylinder blocks and heads," *China Foundry,* vol. 6, pp. 241-246, 2009.

[4] L. L. Myagkov, K. Mahkamov, N. D. Chainov, and I. Makhkamova, "Alternative Fuels and Advanced Vehicle Technologies for Improved Environmental Performance," *Alternative Fuels and Advanced Vehicle Technologies for Improved Environmental Performance,* pp. 370-408e, 2014.

[5] E. Abele, A. Sahm, and H. Schulz, "Wear Mechanism when Machining Compacted Graphite Iron," *CIRP Annals - Manufacturing Technology,* vol. 51, pp. 53-56, 2002.

[6] S. S. Yang, N. Nasr, S. K. Ong, and A. Y. C. Nee, "Designing automotive products for remanufacturing from material selection perspective," *Journal of Cleaner Production,* 2015.

[7] M. Heck, H. M. Ortner, S. Flege, U. Reuter, and W. Ensinger, "Analytical investigations concerning the wear behaviour of cutting tools used for the machining of compacted graphite iron and grey cast iron," *International Journal of Refractory Metals and Hard Materials,* vol. 26, pp. 197-206, 2008.

[8] S. Dawson, I. Hollinger, and M. Robbins, "The effect of metallurgical variables on the machinability of compacted graphite iron," *Detroit, SAE Technical Paper,* vol. 409, pp. 4-16, 2001.

[9] M. B. Da Silva, V. T. G. Naves, J. D. B. De Melo, C. L. F. De Andrade, and W. L. Guesser, "Analysis of wear of cemented carbide cutting tools during milling operation of gray iron and compacted graphite iron," *Wear,* vol. 271, pp. 2426-2432, 2011.

[10] M. Gastel, C. Konetschny, U. Reuter, C. Fasel, H. Schulz, R. Riedel, *et al.*, "Investigation of the wear mechanism of cubic boron nitride tools used for the machining of compacted graphite iron and grey cast iron," *International Journal of Refractory Metals and Hard Materials,* vol. 18, pp. 287-296, 2000.

[11] M. Bazdar, H. R. Abbasi, A. H. Yaghtin, and J. Rassizadehghani, "Effect of sulfur on graphite aspect ratio and tensile properties in compacted graphite irons," *Journal of Materials Processing Technology,* vol. 209, pp. 1701-1705, 2009.

[12] C. Courbon, F. Pusavec, F. Dumont, J. Rech, and J. Kopac, "Tribological behaviour of Ti6Al4V and Inconel718 under dry and cryogenic conditions—Application to the context of machining with carbide tools," *Tribology International,* vol. 66, pp. 72-82, 2013.

[13] G. Rotella and D. Umbrello, "Finite element modeling of microstructural changes in dry and cryogenic cutting of Ti6Al4V alloy," *CIRP Annals - Manufacturing Technology,* vol. 63, pp. 69-72, 2014.

[14] H. Safari, S. Sharif, S. Izman, H. Jafari, and D. Kurniawan, "Cutting force and surface roughness characterization in cryogenic High-Speed End Milling of Ti-6Al-4V-ELi," *Materials and Manufacturing Processes*,Vol. 29, pp.50–356, 2014.

[15] Y. S. Hong and Z. Zhao, "Thermal aspects, material considerations and cooling strategies in cryogenic machining, "*Clean Products and Processes,* vol. 1, pp. 107-116.

[16] S. Y. Hong and Y. Ding, "Cooling approaches and cutting temperatures in cryogenic machining of Ti-6Al-4V," *International Journal of Machine Tools and Manufacture,* vol. 41, pp. 1417-1437, 2001.

[17] B. D. Jerold and M. P. Kumar, "The Influence of Cryogenic Coolants in Machining of Ti – 6Al – 4V," *Journal of Manufacturing Science and Engineering,* vol. 135, pp. 1-8, 2013.

[18] T. C. Yap, N. S. M. El-Tayeb, and P. Von Brevern, "Cutting forces, friction coefficient and surface roughness in machining Ti-5Al-4V-0.6Mo-0.4Fe using carbide tool K313 under low pressure liquid nitrogen," *Journal of the Brazilian Society of Mechanical Sciences and Engineering,* vol. 35, pp. 11-15, 2013.

[19] A. Aramcharoen and S. K. Chuan, "An Experimental Investigation on Cryogenic Milling of Inconel 718 and its Sustainability Assessment," *Procedia CIRP,* vol. 14, pp. 529-534, 2014.

[20] A. Shokrani, V. Dhokia, and S. T. Newman, "Investigation of Cutting Parameters in Sustainable Cryogenic End Milling . In : Second International Conference on Sustainable Opus : University of Bath Online Publication Store Please cite only the published version using the reference above . Please scr," 2015.

[21] A. Shokrani, V. Dhokia, P. Muñoz-Escalona, and S. T. Newman, "State-of-the-art cryogenic machining and processing," *International Journal of Computer Integrated Manufacturing,* vol. 26, pp. 616-648, 2013.

[22] K.-H. Park, B. Ewald, and P. Y. Kwon, "Effect of Nano-Enhanced Lubricant in Minimum Quantity Lubrication Balling Milling," *Journal of Tribology,* vol. 133, p. 031803, 2011.

[23] T. Nguyen, I. Do, and P. Kwon, "A tribological study of vegetable oil enhanced by nano-platelets and implication in MQL machining," *International Journal of Precision Engineering and Manufacturing,* vol. 13, pp. 1077-1083, 2012.

[24] P. L. B. Oxley, *The mechanics of machining : an analytical approach to assessing machinability*. Chichester [England]; New York: E. Horwood ; Halsted Press, 1989.

[25] K.-H. Park, G.-D. Yang, M. A. Suhaimi, D. Y. Lee, T.-G. Kim, D.-W. Kim, *et al.*, "The effect of cryogenic cooling and minimum quantity lubrication on end milling of titanium alloy Ti-6Al-4V," *Journal of Mechanical Science and Technology,* vol. 29, pp. 5121-5126, 2015.

# A Review of Minimum Quantity Lubrication Technique with Nanofluids Application in Metal Cutting Operations

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***Abstract*— Minimum quantity lubrication (MQL) technique did not only serve as a better alternative to flood cooling during machining but enhance better surface finish, reduces the impact loads on the environment and health hazards on the operation personnel. However, the coolant or lubrication media used in MQL technique posed certain restrictions especially at very high cutting speeds where the lubricating oil tends to evaporates as it strikes the already heated cutting tool at elevated temperature. Desire to compensate for the shortcomings of the lubricating media in the MQL technique led to the introduction of nanoparticles in cutting fluids for use in the MQL lubrication process. Nanoparticles have much higher and stronger temperature-dependent thermal conductivity at very low particle concentration, which is considered to be a key parameter for their enhanced performance in many of the applications. Increase of nanoparticles concentration leads to enhanced performance in most of their application. Their ball bearing effect lubrication at the cutting zone through formation of film reduces friction between the contact surfaces thereby reducing cutting force, temperature and tool wear. It has been reported in various studies that nanoparticles in cutting fluids led to enhanced performance in reduction of cutting forces, reduced tool wear, reduced cutting temperature and improved surface finish of the workpiece thereby increasing productivity and reduction of hazards to the health of personnel and the environment better than the pure MQL process. Thus, the application of various nanoparticles and its performances in metal cutting operations with respect to the cutting forces, surface finish, tool wear and temperature at the cutting zone are evaluated and highlighted.***

***Keywords*— Nanofluids; nanoparticles; MQL lubrication; cutting fluid; friction; thermal conductivity.**

## I. INTRODUCTION

Cutting fluids are essential component of machining process as it cools the cutting zone, lubricates the tool chip contact thereby reducing the friction and temperature generated. Even though cutting fluids have a reasonably low cost, their handling and carrying costs are very high and also, owing to their toxic nature, dumping of used fluids is a big problem because of its hazards to workers and also the environment [1,2]. Transition of the Metal Working Industries towards sustainable manufacturing can be seen in the limitation of the use of conventional coolant and coolant strategies [3]. Researches in the machining industry is geared towards achieving green machining environment without compromising efficient machining operation and output. Among the alternative ways of conventional coolant usage reduction, dry machining and those using compressed air and minimum quality lubrication (MQL) technique [4] or using cool air or cryogenic [5] when machining operation is considered as environmentally friendly. MQL technique which has not only provided an alternative to flood cooling or dry machining because of enhanced and efficient machining process, reduction of hazard to operators and the environment also gave better performance with reduced oil consumption, in terms of surface quality of the output product. Several researches indicates that MQL lubrication technique is beneficial to metal cutting process when compared to dry machining, flood cooling, cryogenic cooling or cool air. Sharif et. al [6] reported the MQL technique provides superior lubricity and less wear on the tool during end milling due to the formation of a thin film that protects the tool from excessive wear. MQL in comparison with flood cooling and dry machining drastically minimise (1/300,000 times) the negative effect on the environment and operator's physiology, resulting from ample use of coolant in milling and reduces the cutting force considerably in comparison with dry cutting respectively [7]. However, the MQL technique lubricating oil tends to evaporates as it strikes the already heated cutting tool at high temperature. Thus, the need for high thermal conductivity nanoparticles in cutting fluids are explored to eliminate or reduce drastically the shortcomings of the conventional coolants in MQL techniques. Nanofluids are new classes of fluids engineered by dispersing nanometerized materials (nanoparticles, nanofibers, nanotubes, nanorods etc) in based fluids which could be deionized water, esters or vegetable oils [8].

## II. NANOFLUIDS AND ITS APPLICATION

The concept of nanofluid was first coined by Choi [9] at Argonne National Laboratory but have since then generated much interest due to its great heat transfer enhancement as reported [9, 10], mass transfer [11], and wetting and spreading [12]. It is an established fact that metals in solid form at room temperature, possess higher thermal conductivities than those of base fluids [13]. Investigation conducted by several researchers reveals that nanoparticles enhanced the inherent properties of the based fluid. Lee et. al [14] reported that approximately 20% increase of thermal conductivity was attained when CuO nanoparticles was suspended in ethylene glycol. The thermal conductivity of 0.3% copper nanoparticles in ethylene glycol based fluid increased by 40% in comparison to that of the base fluid [15]. The addition of MWCNT could increase the thermal conductivity of nanofluid up to150% [16]. Nanofluids in comparison with base fluids possess higher thermal conductivity, heat transfer coefficient, viscosity, flash and fire points [17]. Nanofluids can be used to improve heat transfer and energy efficiency in a variety of thermal systems [18]. They are found to have great potential in heat transfer enhancement which made them suitable for practical application in heat transfer processes [19]. The heat transfer enhancement of about 40% can be obtained when compared to the base fluid of $Al_2O_3$ [120]. For CuO-water nanofluid at 2% volume concentration, the overall heat transfer coefficient and pumping power are more than that of base fluid [21]. Nanofluids has been extensively utilised in the convective heat transfer applications. The internal combustion engine performance improved by 10% with the use of nanoparticle suspended in commercial engine coolant [22]. They have much higher and stronger temperature-dependent thermal conductivity and its value increases with particles concentration [23]. This property of nanofluids as shown in Figs. 1a & 1b, is a key parameter for their enhanced performance for many of the applications.

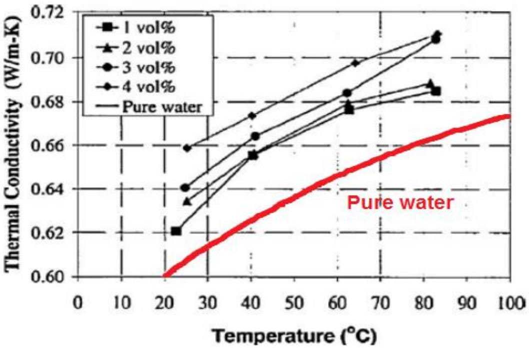


Fig. 1a. Temperature-dependent Thermal Conductivity [23]

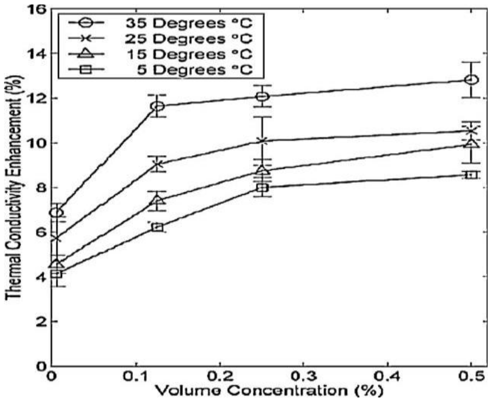


Fig. 1b. Thermal conductivity enhancement as function of volume concentration [23]

### A. *Nanofluid Application with MQL in Machining*

Friction and wear result in the increase of energy consumption and the reduction in the life of mechanical parts. Application of nanofluids as coolant and lubricant results in lower tool temperature, lower tool wear, better surface quality and minimised environmental dangers [24] than most other oils and conventional coolants. Nanofluids are known to enhance the tribological properties of base fluids. Yu Su et. al [25] investigated the tribological properties of graphite nanoparticles as a vegetable based oil additive with a pin-on-disk friction and wear tester. They reported that friction-reducing and anti-wear properties of the pure oil was significantly improved by the graphite nanoparticles addition. Sayuti et al [26] reported that further improvement of the MQL technique was achieved with the introduction of nano lubrication into metal cutting processes which confers rolling action of billions of nanoparticles at the tool chip interface thereby reducing friction and thermal deformation of the workpiece in addition to less consumption of lubricating oil as well as reduced pollution activities. Some of the nanoparticles used for nanofluid application in metal cutting processes includes but not limited to the followings: CuO, $Al_2O_3$, $MoS_2$, CNT, $Fe_3O_2$, nanographite, MWCNTs, nanoboric acid, $SiO_2$, $TiO_2$, nanodiamond, etc. Improvements through the introduction of nanofluid in MQL technique of lubrication during machining operation in all the traditional machining processes are highlighted below.

*1) Grinding Operation:* Nanofluid application with MQL technique in grinding operation have been reported by several researchers. Dinesh et. al [27] studied the effect of nanofluid MQL on the grinding characteristics during the grinding of titanium alloy with silicon carbide grinding wheel, SiC (CGC60-K5-VG) using four different lubrication media (water based Castrol oil cutting oil at 1:40 concentration, pure water and water-based $Al_2O_3$ nanofluids of 1% and 4% concentration). The experiments were conducted on a SMART-H1224 surface grinding machine with the following conditions: grinding parameters: wheel speed (10.89, 16.34 and 21.79 m/sec), table speed (3, 9 and 15 m/min) and depth of cut (10, 20 and 30 µm). The flowrate and air pressure for the MQL grinding are 18ml/hr and 1.5bar respectively. The grinding forces were measured online with a KISTLER 9257B piezoelectric dynamometer, coupled to KISTLER 5070A multichannel (six component) amplifier and computer data acquisition software (Dyno Ware). The mean value was taken after each pass. The ground surface roughness on the other hand was measured by Taylor Hobson Talysurf Profilometer. They reported that grinding forces reduced significantly using nano cutting fluid even at lower concentration of nanoparticles as shown in Fig. 2a, while surface finish improved significantly with increase of nanoparticle concentration when compared with conventional coolant and pure water under MQL. In addition, the cutting force both in normal and tangential were reduced effectively nano-$Al_2O_3$ which can be attributed to the enhanced lubrication and cooling characteristics of the nano-cutting fluid.

Zhang et. al [28] investigated the effect of nanoparticles concentration on the grinding ratio (G) and surface quality of the ground workpiece under MQL grinding of Ni-based alloy. The experiments were conducted using K-P36 numerical control precision surface grinder, nanofluid transfer device (Bluebe MQL supply system) and the measuring cell YDM-III99 3D dynamometer and TIME3220 roughness tester to measure the grinding forces and the surface roughness for all cutting condition respectively. They reported that increase of concentration enhanced lowers grinding force ratio (G) which improves lubrication and better surface quality as shown in Fig. 2b. All the cases of nanoparticle inclusion in MQL indicated a superior performance over pure MQL grinding with grinding force ratio (G) of 0.274, 0.281 and 0.293 for CNTs-$MoS_2$ mixed, $MoS_2$ and CNTs nanofluids respectively as compared to 0.347 of pure MQL lubrication. Shen et. al [29] used water based $Al_2O_3$ and diamond nanofluids in the MQL grinding process. They compared the wheel wear and tribological characteristics in wet (pure water), dry, and MQL grinding processes with nanoparticle grinding of cast iron. They reported a reduction in grinding forces, improved surface roughness and lower grinding temperature with MQL nanoparticles lubricant.

In 2012, Lee et. al. [30] studied the effect of a nanofluid MQL during micro-grinding process of a tool steel material with a CBN 270 grinding tool in a series of experiments under four different lubrication medium (nano-diamond of 2 level concentration, nano-$Al_2O_3$ of 2-level concentration, dry air and pure MQL of the paraffin based oil). The experiments were carried out in a miniaturized grinding machine tool system with the following grinding conditions: spindle speed- 80000 rpm, feed rate 120 mm/min and depth of cut- 5 µm. The flowrate for MQL mist are 7.5 cc/hr for the nanofluid and base oil while the dry air was supplied at 410 l/min. The force signals were obtained by a 2-axis load cell attached to the DC motor-driven slide. Two levels of three independent variables – nanoparticles size, concentration and size were considered in the experiments. The nanoparticles concentration considered are 2% vol. and 4% vol. while particle size of 30nm and 150 nm were selected for both nanodiamond and nano-$Al_2O_3$. They observed that the inclusion of nanoparticles (nanodiamonds and nano $Al_2O_3$) in paraffin oil based MQL produces a significant reduction of grinding forces and improving surface quality in micro-grinding process. In addition, they stated that surface roughness was better enhanced with smaller particle size nanoparticles as they produce smoother surface in comparison with larger particle size of 150nm. Nano-$Al_2O_3$ particles are more effective than nanodiamond particles for reducing surface roughness especially in the case of larger particle size which can easily be attributed to the smaller hardness of nano-$Al_2O_3$ particles than that of the nanodiamond

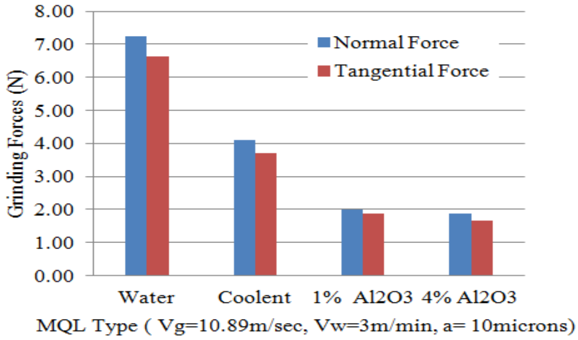

Fig. 2a. Grinding forces using MQL under various cooling media [27].

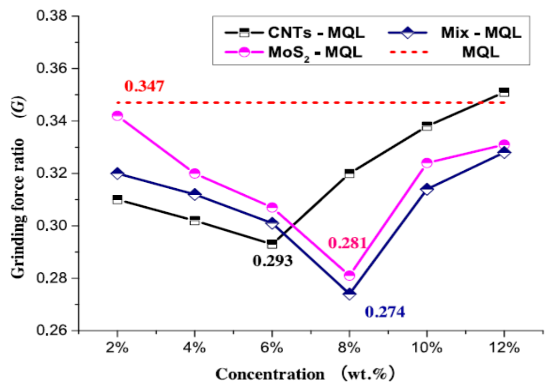

Fig. 2b. grinding force ratios under condition of pure MQL and nanofluids [28]

*2) Drilling Operations:* Drilling operations in metal cutting industries have been enhanced with improved lubrication methodologies. Nam et. al [31] conducted characterization experiment of micro-drilling process using nano-diamond particles suspensions in paraffin and vegetable oils with uncoated carbide twist drills (DIXI 1138) for making of holes in Aluminium 6061 workpiece. The experiment was conducted under the following conditions: spindle speed, feed rate and drilling depth were 60,000 rpm, 50 mm/min and 0.4 mm respectively under four lubrication environment of compressed air, pure MQL of paraffin and vegetable oils and nanofluids of two level inclusion in the paraffin and vegetable oils. The spherical shaped nano-diamond of 30 nm particle size was dispersed at 1% and 2% nano-diamond inclusions in each of the base oils to prepare the nanofluids used for lubrication. The drilling torques and thrust forces during micro-drilling experiments were measured by the torque/load cells. They reported that in addition to significantly increasing the number of drilled holes and reduction of drilling torques and thrust forces, nanofluid MQL enhance the quality of drilled holes due to its effectiveness in elimination of chips inside drilled holes and burrs around it, resulting in enhanced productivity.

Huang et. al [32] evaluated the effect of nanofluid-MQL related parameters (nozzle distance, volume concentration of nanofluid and air pressure) on the micro-drilling of 7075-T6 aluminium alloy with a micro-drill tool (DIXI 1135) of 200µm under different lubrication media of dry, MQL and nanofluid MQL. The variation of the lubrication parameters with thrust force and torque, temperature, tool wear and micro-drilling chips and burrs were investigated. The experiment was conducted under the following condition: spindle speed- 48, 000 rpm, feed rate- 8 µm/rev and drilling depth- 0.52 mm. They opined that the use of nanofluid MQL significantly reduces the micro-drilling force and torque in addition to reducing burr wear in the micro-drilling tool as shown in Fig. 3. Nanofluid inclusion in base fluid enhances the drilling process over the pure MQL and other lubrication as thrust forces and torques are significantly reduced in addition to the efficient removal of chips from drilled holes thereby producing quality holes.

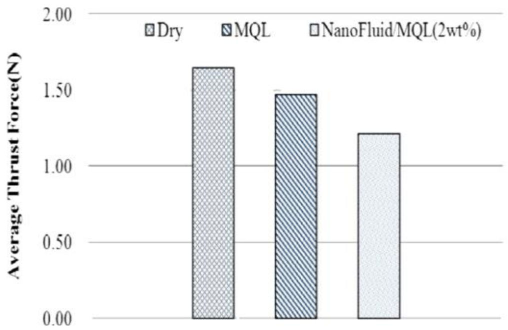


Fig. 3. Effect of thrust force under different lubricating condition of dry, pure MQL and nanofluid MQL [32].

*3) Turning Operation with MQL Nanofluid:* Several researchers reported the enhancement of MQL with nanofluid application. Vasu & Pradeep [33] study the effect of nanoparticle suspension in vegetable oil on surface roughness, tool wear, cutting forces and temperature dissipation during the turning operation of Inconel 600 of 20mm diameter using coated carbide tool inserts (CNMG1 20 408-HF). The experiments were conducted under the following conditions: cutting speed (40, 50 and 60 m/min), feed rate (0.08, 0.12 and 0.16 mm/rev) and depth of cut (0.4, 0.8 and 1.2 mm). $Al_2O_3$ nanoparticle and Coolube vegetable oil with flow rate of 100ml/h were used for lubrication incorporated with MQL technique and dry cutting. The nanolubricant were prepared in two varying concentrations of 4% volume and 6% volume. The surface roughness was measured by a Taylor-Hobson Surtronic 3+ Talysurf while the K-type standard thermocouple and the four-component piezo electric Kistler dynamometer were used to measure the temperature at the interface and the cutting forces respectively. They reported that addition of $Al_2O_3$ nanoparticles in MQL resulted in significant reduction of tool tip temperature, cutting forces and tool wear when compared with dry and pure MQL conditions in addition to better chip formation. The tool wear shown graphically in Fig. 4 and surface roughness improved significantly and was further enhanced with increase of nanoparticle concentration.

Prasad and Srikant [34] studied the effect of nano graphite suspended in water soluble oil with MQL technique during turning of AISI 1040 steel using HSS and cemented carbide (CNMG 120408 H-13A) tools. The effect on cutting force, temperature, surface roughness and tool flank wear were evaluated using the nano cutting fluid lubricant. The experiments were conducted under the following cutting condition: cutting speed of 105 m/min, feed rate of 0.14 mm/rev and 1 mm depth of cut. Nano cutting fluid of nano graphite particles of 80 nm and water soluble oil with flow rates of 5, 10 and 15 ml/min were used for lubrication. The temperature was measured the shielded K-type thermocouple embedded at the bottom of tool holder. The cutting force and the surface roughness were measured by Kistler piezo electric dynamometer model 9272 and Talysurf of diamond stylus material respectively. It was observed that under constant cutting conditions, enhanced reduction in flank wear, cutting temperature, cutting forces and improved surface roughness was achieved with cutting fluids with nanoparticle when compared with pure cutting fluid.

Yu Su et. al [35] investigated the effect of nanographite dispersed in vegetable-based oil and ester oil as base fluid during turning of AISI 1045 steel with two cutting inserts of uncoated carbide. They reported that application of graphite oil-based nanofluid MQL significantly reduced the cutting force and temperature as shown in Fig. 5. Padmini et al [36] evaluated the performance of vegetable oil based nanofluid with dispersion of molybdenum sulphide nanoparticle ($nMoS_2$) in different based oils of coconut (CC), canola (CAN) and sesame (SS) in turning AISI 1040 steel. Experiments were conducted under the following cutting conditions: cutting speed (40, 60 and 100 m/min), feed rate (0.14, 0.17 and 0.2 mm/rev) and constant depth of cut of 0.5 mm. Machining conditions are selected in conformity with tool and workpiece combination and MQL flowrate of 10 ml/min. The nanofluids were prepared with nanoparticle inclusion of 0.25%, 0.5%, 0.75% and 1.0% in all the base oils. The cutting force were measured using Kistler dynamometer 5070 which is fixed to the lathe tool post and the measured forces tracked using dynoware software. Based on their observation, basic properties of nanofluids increased with increase nanoparticle inclusion in the base fluids. In addition, CC+0.5%$nMoS_2$ exhibited better performance over the other nanofluids and the cutting force, cutting temperatures, tool wear and surface roughness were reduced by 37%, 21%, 44% and 39% respectively when compared with dry machining.

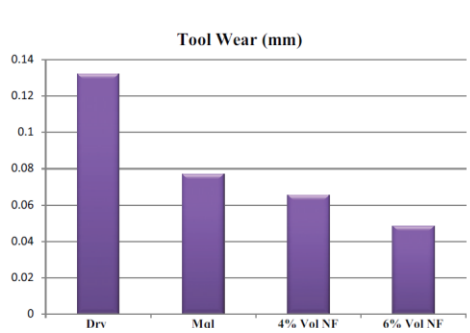


Fig. 4. Response graph at optimal parameters for tool wear [33]

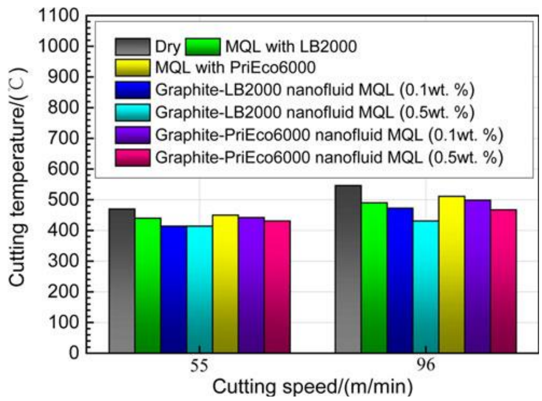


Fig. 5. Variation in cutting temperature with cutting speed for various cooling/lubrication conditions [35]

*4) Milling Operation with MQL Nanofluid:* Nanofluid integrated with MQL lubrication has been used to improve machining performance of milling operations. Huang et. al [37] investigated and compared the effects of optimal MQL integrated with MWCNTs with dry cutting and pure MQL on the cutting force, cutting temperature, tool wear and surface roughness under same cutting conditions: cutting speed (100, 150 and 200 m/min), feed rate (0.05, 0.1 and 0.2 mm/tooth), coolant angle of ejection (90º, 180º and 270º) and nanofluid concentration (0, 0.25 and 0.5 wt.%). The cutting force and cutting temperature were measured by a KISTLER dynamometer and a FLIR A320 infrared thermal imager respectively. The surface roughness meter (Mitutoyo, SJ-210) was used to detect the surface quality. Tool wear value were measured with SEM (JSM-6380, JEOL) and a measuring microscope. They reported that MWCNTs-MQL provided efficient lubrication and the superior thermophysical properties of the nanofluid enhanced rapid elimination of excessive friction and heat from the tool and workpiece interface. The cutting temperature as indicated in Fig. 6 and tool wear are therefore reduced more effectively which enhanced surface finish than dry cutting or pure MQL.

Sayuti et. al [38] investigated the effects of tribological properties of carbon onion nanotubes in mineral oil, on the cutting force reduction and surface quality improvement during CNC end-milling of Duralumin AL-2017-T4 under MQL lubrication. The machining test was carried out on vertical machining centre (Sakai CNC MM-250 S3) with a maximum rotational speed of 5,000 m/min. The workpiece of dimension 50x20x10mm$^3$ was machined under the following cutting conditions: cutting speed, feed rates, and depths (75.408 m/min, 100 mm/min, and 1.0 mm), respectively, based on the recommendations given by the tool manufacturer. Alumicut lubricant mineral based oil was chosen for lubrication because of its favourable lubrication characteristics to reduce friction at the tool-chip interface. They reported that carbon onion nanotubes are capable of lowering the cutting force and reducing temperature at cutting zone thereby reducing wear rate and thus enhance surface finish. It was observed that the MQL nanofluid lubrication gave better performance than the pure MQL and the reduction of cutting force and surface roughness improvement were further enhanced at higher carbon nanotubes concentration as shown in Fig. 7. The cutting force reduction and surface roughness improvement are found to be 21.99% and 46.32% respectively when compared with the ordinary lubrication system at same cutting conditions. The results are mainly attributed to the enhanced tribological properties of the carbon onion nanotubes, which act as billions of nanoscale quasispherical structure rolling elements at the tool-chip interface thereby reducing significantly coefficient of friction at the zone.

Park et. al [39] investigated the effect of nanographene enhanced lubricant during ball milling of AISI 1045 steel with a 25mm diameter ball-nose TiAlN coated carbide inserts (ZPFG250-PCA 12M) under MQL nanofluid (0.1 and 1 wt.%) and pure vegetable oil MQL. The ball milling experiments were conducted under the following cutting parameters: cutting speed range (3500 and 4500 rpm), constant feed rate of 2500 mm/min and depth of cut (axial – 1 mm and radial – 0.6) to evaluate the effect of the lubrication techniques on the flank and central wears. They reported that nanographene enhanced lubricant exhibited better performance than the pure MQL especially for the central wear.

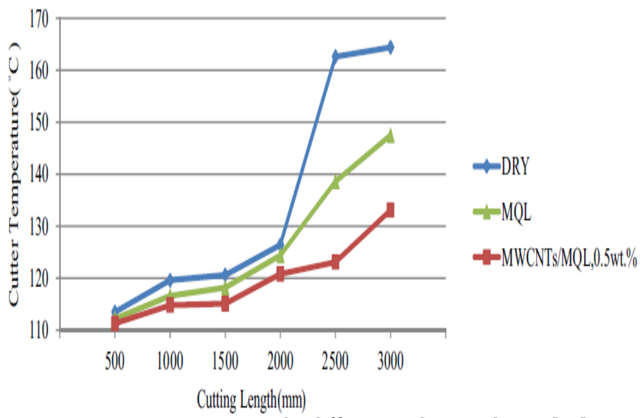


Fig. 6. Cutting temperature under different coolant conditions [37].

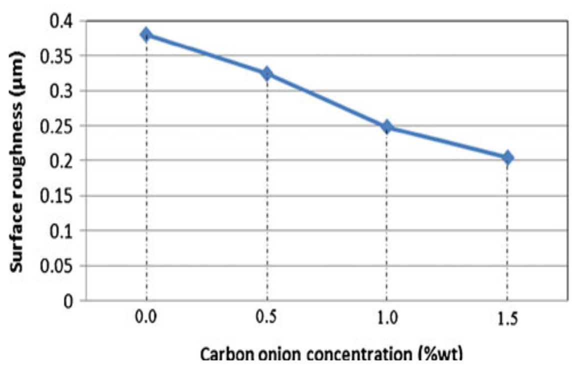


Fig. 7. Surface roughness recorded at different carbon onion concentration [38]

## III. EFFECT OF NANOFLUID MQL ON MACHINING PARAMETERS

Nanofluid integration with MQL has improve machining output over time in comparison with pure MQL or other lubrication methods. Machining parameters such as cutting force, cutting temperature, tool and flank wear, surface roughness etc have improved greatly in addition to reduction of loads on the environment and enhanced safety of the personnel. The cutting force in grinding [27,29-30], drilling [31], turning [33-36] and milling [37-38] decreased significantly with the use of nanofluid integrated with MQL technique when compared to pure MQL and other lubrication medium. From Fig. 2a, the comparison of nanofluid MQL with water and conventional coolant under MQL indicated superior performance of the nanofluid MQL lubrication. The force reduction could be attributed to the enhanced lubrication and cooling characteristics shown by nanofluids. Fig. 2b shows the how increase of volume concentration of nanoparticles lowers the grinding force ratio (G) which is important criteria for enhanced lubrication in grinding. The optimum value of the grinding force ratio was attained at 8% for CNTs-$MoS_2$ mixed and $MoS_2$ while CNTs at 6%. Increase of concentration beyond these optimum nanoparticle concentrations may result in agglomeration thereby increasing G-value that may impede efficient lubrication.

Surface roughness of machined component is always enhanced with nanofluid MQL than other lubrication method as efficient lubrication reduces cutting force, friction between workpiece-tool interface and conduction of heat away from the cutting zone [37]. The surface roughness of machined component is further enhanced with increase of nanoparticles concentration in base cutting fluid as shown in Fig. 7. Similarly, increase of nanoparticle concentration in vegetable oil from 0.1wt% to 0.5wt% in comparison with ester oil at same level of increment indicated a superior performance of the vegetable oil based nanofluid over the ester oil based nanofluid as can be seen in Fig. 5. The temperature generated in machining is reduced with the elimination of excessive friction and heat away from workpiece and tool interface. The superior performance of nanofluid MQL over pure MQL is indicated in Fig. 6 in terms of temperature reduction. The tool wear has great impact on the surface finish of the machined component and the tool life of the cutting tool. The use of nanofluid integrated with MQL in machining reduces the cutting forces, temperature which influence reduction of excessive tool wear and elongation of tool life. Fig. 4 indicated a reduction of tool wear in MQL nanofluid in comparison with pure MQL and dry cutting. The tool life was enhanced by 45% with MQL 6% $Al_2O_3$ in MQL as coolant when compared to dry cutting.

## IV. CONCLUSION

Cooling and lubrication are very important in metal cutting process due to the reduction of negative effect resulting from interaction of cutting tool and workpiece. The introduction of nanoparticles in base cutting fluid into MQL lubrication technique and its improvement of lubrication and cooling has been reported by researchers. The effect of increase of volume concentration as it affects the thermal conductivity of nanofluid and its subsequent performance in application were evaluated. The performance of nanofluid integrated with MQL in metal cutting in the areas of reduction of cutting force, cutting temperature, grinding force ratio (G) in grinding, surface roughness improvement, tool wear reduction thereby elongating tool life and the safety of environment and personnel are highlighted.

## ACKNOWLEDGMENT

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## REFERENCES

[1] J. P. Byers, Metal Working Fluids, 1st ed., USA: CRC, 1994.

[2] Y. Wei and X. Huaqing, "A review on nanofluids: preparation, stability mechanisms and applications", Journal of Nanomaterials, vol. 2012, pp. 1-17, 2012.

[3] K. Weinert, I. Inasaki, J. W. Sutherland and T. Wakabayashi, "Dry machining and minimum quantity lubrication", CIRP Annals - Manufacturing Technology, vol. 53, pp. 511-537, 2004.

[4] T. Tawakoli, M. J. Hadad, M. H. Sadeghi, A. Daneshi, S. Stöckert and A. Rasifard, "An experimental investigation of the effects of workpiece and grinding parameters on minimum quantity lubrication—MQL grinding", International Journal of Machine Tools and Manufacture, vol. 49, pp. 924-932, 2009.

[5] H. Safari, S. Sharif, S. Izman, H. Jafari, and D. Kurniawan, "Cutting force and surface roughness characterization in cryogenic high speed end milling of Ti6Al4V ELI", Materials and Manufacturing Processes, vol.29, Issue 3, pp. 350-356, 2014.

[6] S. Sharif, M. A. Hisyam, D. Kurniawan and E. A. Orady, "Performance evaluation of vegetable oil as an alternative cutting lubricant when end milling stainless steel using TiAlN coated carbide tool", Transaction of the North American Manufacturing Research Institution of SME, vol. 37, pp. 9-13, 2009.

[7] M. Rahman, A. Senthil Kumar and M. U. Salam, "Experimental evaluation on the effect of minimal quantities of lubricant in milling", International Journal of Machine Tools & Manufacture, vol. 42, pp. 539–547, 2002.

[8] I. Manna, "Synthesis, characterization and application of nanofluid - An overview", Journal of the Indian Institute of Science, vol 89:1, pp. 21-33, 2009.

[9] S.U.S. Choi, "Enhancing thermal conductivity of fluids with nanoparticles: Developments and applications of Non-Newtonian flows", ASME' 95, paper CONF-951135-29, pp.1-8.

[10] H. Masuda, A. Ebata, K. Teramae and K. Hishiunma, "Alternation of thermal conductivity and viscosity of liquid by dispersing ultrafine particles (dispersion of $Al_2O_3$, $SiO_2$ and $TiO_2$ ultrafine particles)", Netsu Busei, Japan, 1993, pp. 227-233.
[11] S. Krishnamurthy, P. Bhattacharya, P. E. Phelan and R. S. Prasher, "Enhanced mass transport in nanofluids", Nano Letter 6, vol. 3, pp. 419 – 423, 2006.
[12] D. T. Wasan, and A. D. Nikolov, "Spreading of nanofluids on solids", Nature 423, pp. 156–159, 2003.
[13] Y. S. Touloukian, R. W. Powell, C. Y. Ho, and P. G. Klemens, "Thermo-Physical Properties of Matter", New York, USA, Plenum Press, 1970, vol. 2
[14] S. Lee, S.U.S. Choi, S. Li, and J. A. Eastman, "Measuring thermal conductivity of fluids containing oxide nanoparticles", ASME Journal of Heat Transfer vol. 121, Issue 2, pp. 280-289, May 1999.
[15] J. A. Eastman, S.U.S. Choi, S. Li, W. Yu and L. J Thompson, "Anomalously increased effective thermal conductivities of ethylene glycol based nanofluids containing copper nanoparticles", Applied Physics Letter, 78 (6), 718 – 720, 2001.
[16] T. Tun-Ping and Y. Chao-Chieh, "Heat dissipation performance of MWCNTs nano-coolant for vehicle", Experimental Thermal and Fluid Science, 49, pp. 22-30, 2013.
[17] Y. Hwang, H. S. Park, J. K. Lee and W. H. Jung, "Thermal conductivity and lubrication characteristics of nanofluids". Current Applied Physics, vol. 61 pp.67–71, 2006.
[18] X. Wang and A. S. Mujumdar, "A review on nanofluids - Part II: Experiments and Applications", Brazilian Journal of Chemical Engineering vol. 25, No. 04, pp. 631- 648, 2008.
[19] W. Daungthongsuk and S. Wongwises, "A critical review of convective heat transfer of nanofluids", Renewable and Sustainable Energy Reviews II, pp.797–817, 2007.
[20] J. Albadr, S. Tayal and M. Alasadi, "Heat transfer through heat exchanger using $Al_2O_3$ nanofluid at different concentrations, Case Studies in Thermal Engineering", vol. 1, Issue 1, pp.38–44, October, 2013.
[21] I. M. Mahbubul, R. Saidur, and M.A. Amalina, "Latest developments on the viscosity of nanofluids", International Journal of Heat and Mass Transfer, vol. 55, pp. 874–885, 2012.
[22] S.U.S. Choi D. A. Singer and H. P. Wang, "Development and Application of Non-Newtonian Flows", Vol. FED 231. New York: ASME; 1995. 99–105.
[23] R. Saidur, K. Y. Leong and H. A. Mohammad, "A review on applications and challenges of nanofluids" Renewable and Sustainable Energy Reviews, vol. 15 pp. 1646–1668, 2011.
[24] Y. Shokoohi and E. Shekarian, "Application of nanofluids in machining processes - A review", Journal of Nanoscience and Technology, vol. 2 (1), pp. 59 – 63, 2016.
[25] M. Sayuti, O. M. Erh, A. D. Ahmed Sarhana and M. Hamdi, "Investigation on the morphology of the machined surface in end milling of aerospace AL6061-T6 for novel uses of $SiO_2$ nanolubrication system", Journal of Cleaner Production, vol. 66, pp. 655-663, 2014.
[26] Y. Su, G. Le and C. Dandan, "An investigation on tribological properties and lubrication mechanism of graphite nanoparticles as vegetable based oil additive", Journal of Nanomaterials, Vol. 16, pp. 1-7, 2015.
[27] D. Setti, S. Ghosh, and P. Venkateswara Rao, "Application of nano cutting fluid under minimum quantity lubrication (MQL) technique to improve grinding of Ti-6Al-4V alloy", World Academy of Science, Engineering and Technology, vol. 6, pp. 10-24, 2012.
[28] Y. Zhang, C. Li, D. Jia, B. Li, Y. Wang, M. Yang, Y. Hou and X. Zhang, "Experimental study on the effect of nanoparticle concentration on the lubricating property of nanofluids for MQL grinding of Ni-based alloy", Journal of Materials Processing Technology, vol. 232, pp. 100 -115, 2016.
[29] B. Shen, A. J. Shih and S. C. Tung, "Application of nanofluids in minimum quantity lubrication grinding", Tribology Transactions, vol. 51, No. 6, pp. 730-737, 2008.
[30] P. Lee, J. S. Nam, C. Li and S. W. Lee, "An experimental study on micro grinding process with nanofluid minimum quantity lubrication (MQL)", International Journal of Precision Engineering and Manufacturing vol. 13, No. 3, pp. 331-338, 2012.
[31] J. S. Nam, P. H. Lee and S. W. Lee, "Experimental characterization of micro-drilling process using Nanofluid minimum quantity Lubrication", International Journal of Machine Tools & Manufacture, vol. 51, pp. 649-652, 2011.
[32] W. T. Huang, D. H. Wu and J. T. Chen, "Robust design of using nanofluid/MQL in micro-drilling", International Journal of Advanced Manufacturing Technology, pp. 1-7, June 2015a.
[33] V. Vasu and G. Pradeep Kumar Reddy, "Effect of minimum quantity lubrication with $Al_2O_3$ nanoparticles on surface roughness, tool wear and temperature dissipation in machining Inconel 600 alloy", Proc. IMechE, 2011 Vol. 225 Part N: Journal of Nanoengineering and Nanosystems.
[34] M. M. S. Prasad and R. R. Srikant, "Performance evaluation of nano-graphite inclusions in cutting fluids with MQL technique in turning of AISI 1040 steel", International Journal of Research in Engineering and Technology, vol. 02, Issue 11, pp. 381-393, Nov. 2013.
[35] Y. Su, L. Gong, B. Li, Z. Liu and D. Chen, "Performance evaluation of nanofluid MQL with vegetable-based oil and ester oil as base fluids in turning", International Journal of Advanced Manufacturing Technology, vol 83, pp. 2083–2089, 2016.
[36] R. Padmini, P. Vamsi Krishna and G. Krishna Mohana Rao "Effectiveness of vegetable oil based

nanofluids as potential cutting fluids in turning AISI 1040 steel", Tribology International, vol. 94, pp. 490-501, 2016.

[37] W. T. Huang, D. Wu, S. Lin and W. Liu, "A combined minimum quantity lubrication and MWCNT cutting fluid approach for SKD 11 end milling", International Journal of Advanced Manufacturing Technology, pp. 1-8, 2015.

[38] M. Sayuti, A. D. Ahmed Sarhan, T. Tanaka, M. Hamdi and Y. Saito, "Cutting force reduction and surface quality improvement in machining of aerospace duralumin AL-2017-T4 using carbon onion nanolubrication system", International Journal of Advanced Manufacturing Technology, vol. 65, pp. 1493 – 1500, 2013.

[39] P. Kyung-Hee, B. Ewald & P. Y. Kwon, "Effect of nano-enhanced lubricant in minimum quantity lubrication ball milling", Journal of Tribology, Transactions of the ASME, vol. 133, pp. 031803:1-8, July 2011.

# Properties of Metal Filled Epoxy for Injection Mould Inserts

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**Abstract:** Metal filled epoxy is an alternative material used in rapid tooling such as core and cavity for injection moulding. Fillers increase epoxy's mechanical performance such as wear, strength, improved machinability and thermal properties. In this study, metal fillers such as copper and brass were blended into the epoxy matrix, altering the density, thermal values, and compressive strength. They were added separately ranging from 10%, 20% and 30% of its weight into the aluminium filled epoxy mix ratio. Increased density and thermal diffusivity values were observed with a linear trend when both filler compositions were increased from 10% to 30%. Brass and copper density values are 2.22 g/cm$^3$ and 2.08 g/cm$^3$ respectively at highest filler composition. Copper fillers with 30% composition in epoxy matrix exhibited the highest average value of thermal diffusivity of 1.12 mm$^2$/s, while brass showed no significant improvements. Compressive strength values increased from 76.8 MPa to 93.2 MPa with brass fillers at 20% and 80.8 MPa with copper fillers at 10% composition. The addition of more fillers resulted in a decrease in compressive strength due to internal porosity. This study validated previous researchers that fillers enhance mechanical and thermal properties and density of Aluminium filled epoxy.

**Keywords:** Epoxy; Fillers; Density; Thermal diffusivity; Compressive strength

## 1. INTRODUCTION

Tooling design such as plastic injection moulds and metal stamping dies consist of extensive steps in manufacturing processes due to the stringent requirements of the end product, where dimensional accuracy and good surface finish are paramount. Mould and die components are fabricated from conventional, CNC and electro discharge machining processes that are expensive and time-consuming methods. Manufacturers can take advantage of rapid prototyping (RP) and rapid tooling applications to produce parts for short run production for cost optimisation, instead of building hard tooling. Pouzada outlined faster delivery periods, higher demand for quality, reduced product development phase and adapting to globalisation made industries apply alternative production methods for example like alternative materials and rapid tooling [1].

Application of rapid tooling aims to cut cost and reduce production time, hence several methods has been explored via direct and indirect tooling methods. Direct methods utilise rapid prototyping to build inserts or moulds, while indirect techniques manipulate RP as master patterns to produce a mould or castings [2]. Adding metallic fillers increased the thermal conductivity of the epoxy matrix, for example, aluminium or copper are added, while adding milled carbon or glass fibres improves mechanical properties such as wear resistance [3]. This also increased the density of the epoxy composition, further improving mechanical performance for tooling purpose. This paper is to investigate the material density, compressive strength and thermal diffusivity.

## 2. METHODOLOGY

### A. Samples preparation

Epoxy with aluminium filled (EA), RenCast CW 47 from Huntsmann Advanced Materials is mixed with its hardener Ren HY 33 at a ratio of 100:15 [4]. Aluminium particles with concentration between 25% – 30% in the epoxy mixture, while brass and copper particles were added separately to the EA concentration, based on 10%, 20% and 30% of the mixture weight. The mixtures were poured into rubber moulds with specific test shapes for compressive strength, hardness, wear test and thermal conductivity, and then went through a final degassing process (Fig. 1). Recommended mixture and degassing procedures were followed, and pre-cured at 50°C overnight and cured at 180°C for 14 hours. Temperature increase was set at 1°C/minute and allowed to cool in the oven to ambient temperature.

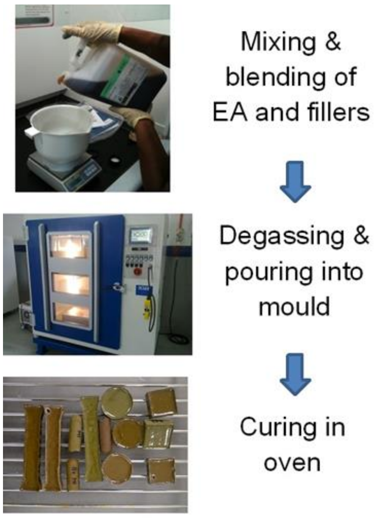


**Fig.1. Aluminium filled epoxy preparation with filled metals**

B. Density Test

RenCast CW 47 filled epoxy resin has the initial density of 1.85 g/cm$^3$ [4], while other commercially available materials are between 1.7 to 2.0 g/cm$^3$ [5]. Samples containing mixtures of brass and copper in the epoxy matrix were cut into small sizes, weighed in air and water to determine the relative densities. This method corresponds to ASTM D-792 -13, and the relative density, $D$ (at 20°C) is determined by (1):

$$D = \frac{a - b}{a - b + c - d} \qquad (1)$$

Where;

$a$ = mass of specimen and wire in air
$b$ = mass of wire in air
$c$ = mass of wire with end immersed in water
$d$ = mass of wire and specimen immersed in water

C. Thermal Diffusivity Test

Cured epoxy samples were milled to achieve 5 mm thickness, and 2 pieces of ϕ30 discs were prepared for thermal diffusivity test. Thermal conductivity analyser model TPC 2500s with hot wire thermal constants analyser software version 5.9 were used for this purpose, equipped with Kapton® insulated sensor that operates between -160°C to 300°C (Fig. 2). Samples were tested with output power set at 0.05W and 200 points recorded within 10 seconds, according to ASTM C1113.

Thermal diffusivity is described as how material or solid can change its temperature [6]. Thermal diffusivity has a unit of m$^2$/s, and represented by (2):

**Fig.2. Kapton® insulated sensor in between ϕ30 mm disc samples**

$$\alpha = k / \rho c \qquad (2)$$

Where ;

$\alpha$ = Thermal diffusivity (mm$^2$/s)
$k$ = Thermal Conductivity (W.m/K
$\rho$ = Density of material (kg/m$^3$)
$c$ = Specific heat of material (J/kg.K)

D. Compressive Strength Test

ASTM D 695 was employed considering that the epoxy material is a rigid thermoset class of material [7]. A support jig was fabricated to hold the specimen upright, together with top and bottom platens for the compressive test, in Fig 3. Mild steel platens were fabricated with surface diameter of ϕ100mm x 10 mm thick, with primary function to support the jig. Instron 3300 series Universal Testing Machine with maximum force of 5 kN, was used for the testing purpose. Compressive strength specimens were prepared with length 79.4mm x width 19mm, while the neck area was 13mm wide and 5mm thickness. Specimens consisting of different filler percentages were clamped between the jigs and subjected to a load at 10 mm/min.

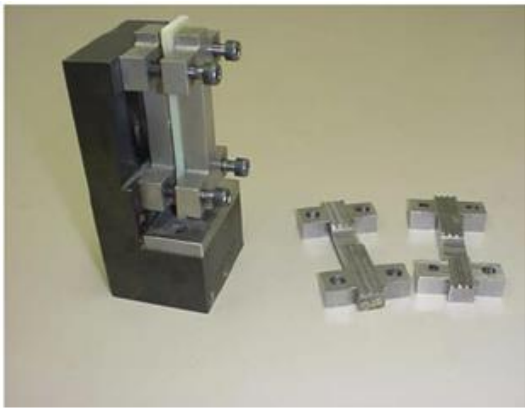

**Fig.3. Support jig for ASTM D 695 [8]**

## 3. RESULTS & DISCUSSION

A. Density Test

The previous study with metallic and non-metallic fillers indicated that density increase with the addition of fillers percentage. For example, one study used epoxy resins (LY556 resin of M/S Ciba Geigy) with SiC, graphite, copper and aluminium showed linear trends with an increase of filler composition [9].

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Similar trends were indicated when gypsum, alumina and silicon nitride mixed with epoxy and measured in Shore D hardness [10]. Both fillers increased the density of cured mixture as indicated in Table I.

TABLE I. AVERAGE DENSITY OF EA WTH FILLERS, $g/cm^3$

| | Composition of weight, % | | |
|---|---|---|---|
| **Fillers** | **10%** | **20%** | **30%** |
| Brass | 1.85 | 2.01 | 2.22 |
| Copper | 1.83 | 1.96 | 2.08 |

B. Thermal Diffusivity

Average thermal diffusivity of epoxy with aluminium filled is 0.70 $mm^2/s$ where adding fillers altered the values. Brass fillers reduced the values at 10% & 20% composition and only improved when 30% brass filler were added to the mixture, an increase of 0.04 $mm^2/s$ compared to the original value. Copper filler provided better thermal diffusivity values as compared to brass indicated in Table II. Improved thermal diffusivity will directly increase thermal conductivity based on the equation given [4]. This is supported by a study that silicon carbide (SiC) improved thermal conductivity from 0.45 to 1.3 W.m/K from 0% to maximum of 40% SiC powder, added into the epoxy mixture [11].

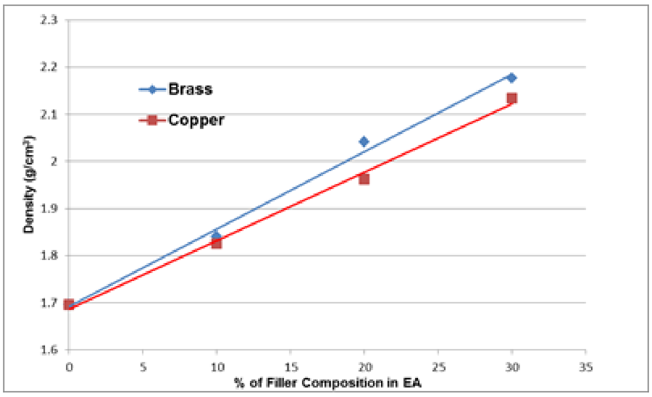


Fig.4. Effects of Fillers on EA Density

TABLE II. AVERAGE THERMAL DIFFUSIVITY OF EA WTH FILLERS, $mm^2/s$

| | Thermal Diffusivity ($mm^2/s$) | | |
|---|---|---|---|
| **Fillers** | **10%** | **20%** | **30%** |
| Brass | 0.644 | 0.657 | 0.740 |
| Copper | 0.837 | 0.923 | 1.112 |

C. Compressive Strength Results

Samples exhibited deflection and crack at the neck area (Fig. 6) when reaching the maximum load. The individual data were collected and represented in the stress-strain diagram, where strain is calculated from the decreased deflection during the test. The stress – displacement diagram is indicated in Fig. 7. Based on Table III, 20% brass fillers demonstrated the highest average value of 93.23 MPa and reduced strength at 30% composition.

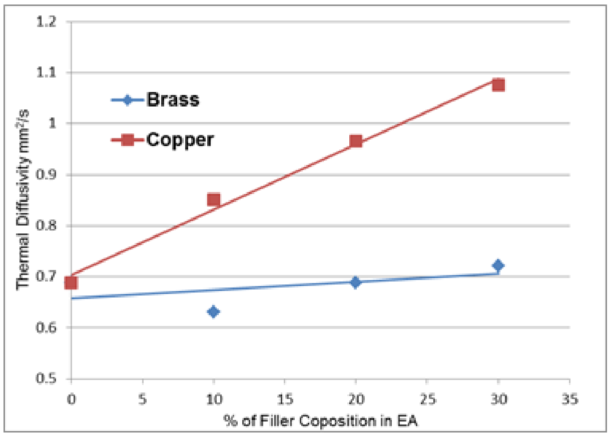


Fig.5. Effects of Fillers on EA Thermal Diffusivity

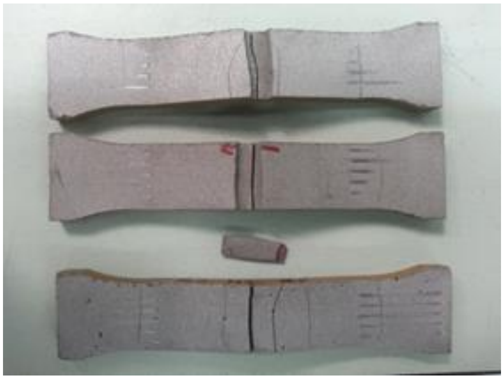

Fig.6. Visible cracks after compression tests

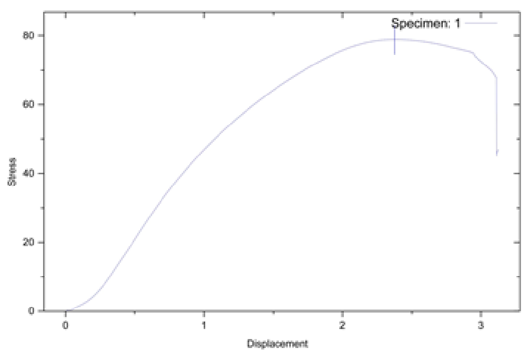


Fig.7. Compressive Stress (MPa) vs. Displacement (mm)

TABLE III. COMPRESSIVE STRENGTH VALUES OF EA WTH FILLERS, MPa

| | Compressive Strength (MPa) | | |
|---|---|---|---|
| **Fillers** | **10%** | **20%** | **30%** |
| Brass | 95.61 | 93.23 | 92.69 |
| Copper | 80.83 | 81.51 | 73.17 |

Copper fillers showed a downward trend of the compressive strength (Fig 8). This is contrary with a study that mentioned higher copper filler percentages improved the compressive strength of samples because fillers aided the resistance of the material under load [12].

This is due to the low thickness of the test samples which are 5 mm, in order to simulate ribs and bosses in mould cavities.

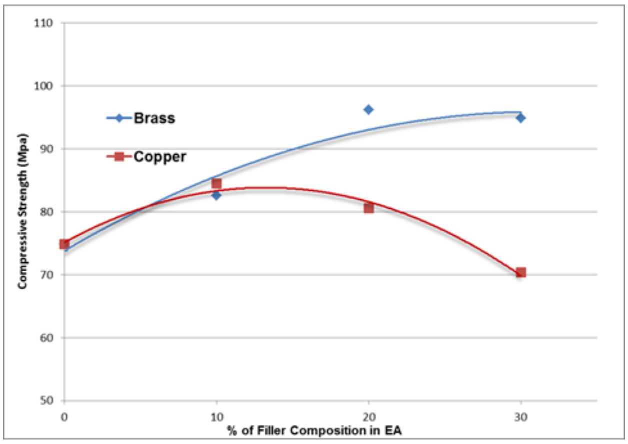


**Fig.8. Effect of filler composition on compressive strength in EA**

Figs. 9a, b and c show the dispersion of copper fillers in the samples, where trapped air is observed as black patches. White particles are aluminium with an average size of 5.7μm to 10.7μm. Trapped air or voids is porosity that existed in copper mixed with EA. More copper fillers resulted in higher porosity, because trapped air takes a longer time to be released although the dispersion of both fillers was uniform throughout the matrix. The average percentage of voids in EA with copper and brass fillers were determined with Huvitz HRM-300 high power microscope, equipped with 10x digital magnification camera. Images were processed with digital microscopy analyser software (IMT ISolution DT).

There were fewer air pockets indicated in the brass mixture samples. This was evident in the composition analysis using ASTM E1245. Table IV indicates the percentage of mean distribution of voids, identified as trapped air in EA mixture with individual fillers.

**TABLE IV. VOID AREA BY PERCENTAGE IN EA COMPOSITION**

| | Average % of voids (by Area) | | |
|---|---|---|---|
| **Fillers** | **10%** | **20%** | **30%** |
| Brass | 0.8 | 0.8 | 1.2 |
| Copper | 2.1 | 3.7 | 5.9 |

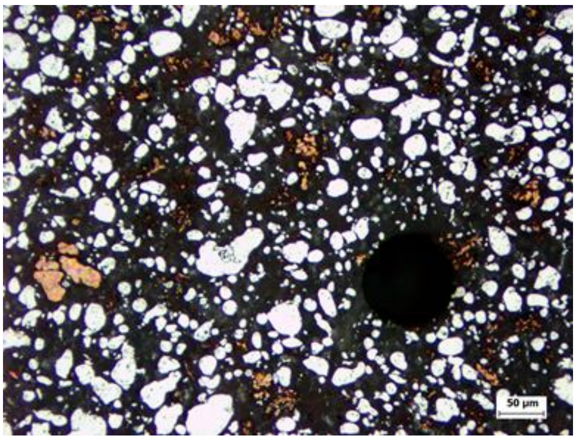


**Fig.9a. Void in EA with 10% copper fillers**

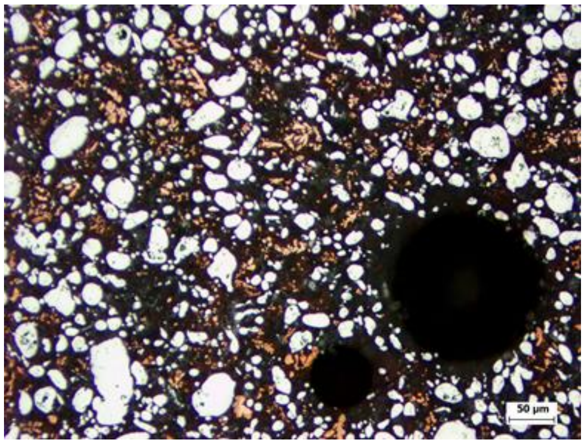


**Fig.9b. Void in EA with 20% copper fillers**

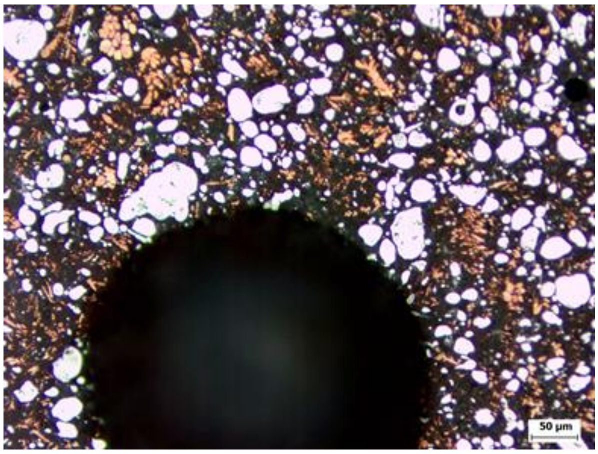


**Fig.9c. Void in EA with 30% copper fillers**

From the data observation, maximum diameter of voids increased from 10% to 30% of copper fillers. Voids are represented by equal circle diameter as trapped air that formed a round shape. Table V shows that void diameters in EA and brass filler composition are consistent is size, as compared with copper.

**TABLE V. MAXIMUM SIZE OF VOIDS IN EA COMPOSITION, μm**

| | Maximum size of voids (μm) | | |
|---|---|---|---|
| **Fillers** | **10%** | **20%** | **30%** |
| Brass | 43.1 | 40.2 | 41.8 |
| Copper | 66.8 | 134.9 | 171.1 |

## 4. CONCLUSION

In this study, the following conclusions were drawn:

1. The brass and copper concentration in aluminium filled epoxy (EA) significantly affects the density of the mixture, indicating a linear increase with higher filler weight. Brass exhibited density value of 2.22 g/cm$^3$ at 30% of its composition weight. This will improve the mould insert performance in terms of durability and machinability.

2. Thermal diffusivity was observed to increase with higher copper concentration up to 1.112 mm$^2$/s, which is a 59% gain from the value of EA without fillers. Adding brass did not significantly improve it's thermal properties. However at 30% of brass fillers, the value increased to 0.74mm$^2$/s compared to

the unfilled EA at 0.7 $mm^2/s$. Heat dissipation is an important factor in order to cool the insert rapidly and enable stress relief in the moulded part during solidification.

3. Brass exhibited higher compressive strength compared to coppers fillers in EA, however filler ratio beyond 20% in the composition will reduce the strength. This effect is similar in copper fillers since voids were found in the samples resulting in samples breakage more apparent. The void areas increased with increased in the filler ratio to EA mixture.

## ACKNOWLEDGMENTS:

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## REFERENCES

[1] A.S. Pouzada. Hybrid moulds: A case integration of alternative materials and rapid prototype for tooling, Virtual and Physical Prototyping, Vol. 4, No. 4, (2009) 195 – 202.

[2] P. Dunne, S.P. Soe, G. Byrne, A. Venus, A.R. Wheatley. Some demands on rapid prototypes used as master patterns in rapid tooling for injection moulding, Journal of Materials Processing Technology, 150 (2004) 201 – 207.

[3] P.V. Vasconcelos, F.J. Lino, A. Magalhães, Baptisa, R.J.L. Neto, Impact fracture study of epoxy-based composites with aluminium particles and milled fibres, Journal of Materials Processing Technology, 170 (2005) 277 – 283.

[4] RenCast CW47 Datasheet March 2007. Huntsman Adv. Materials GmbH, Switzerland.

[5] Handling Procedure Mould Production with MCP Tooling Resins - EP 310 (version 3). MCP-HEK Tooling GmbH, Germany.

[6] N.S. Gokhale, S.S. Deshpance, S.V. Bedekar, A.N. Thite (2008). Practical Finite Element Analysis – 1st Edition, Finite to Infinite : Pune, India.

[7] T.L. Richardson, E. Lokensgard (1996). Industrial Plastics, Theory and Applications, Delmar Publishers Inc : New York.

[8] A.R. Wolfe, M.Weiner. Compression Testing - Comparison of Various Test Methods, Composites 2004 Convention and Trade Show American Composites Manufacturers Association October 6-8, 2004 Tampa, FL USA.

[9] M.S. Bhagyashekar, K. Rao & M.V.G.K. Rao. Studies on rheological and physical properties of metallic and non-metallic particulate filled epoxy composites, Journal of Reinforced Plastics and Composites, 28 (2009) 2869 – 2878.

[10] S. Ma, I. Gibson, G. Balaji, Q.J. Hu. Development of epoxy matrix composites for rapid tooling applications, J. of Mat. Proc. Tech, (2007) 192-193, 75-82.

[11] T. Tomori, S. Melkote & M. Konis. Injection Mould Performance of Machined Ceramic Filled Epoxy Tooling Boards, Journal of Materials Processing Technology, 145 (2004) 126-133.

[12] M.S. Bhagyashekar, M.V.G.K. Rao. Characterization of mechanical behaviour of metallic and non-metallic particulate filled epoxy matrix composites. J. of Reinforced Plastics and Composites, 29: 30 (2010) 30 – 42.

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# Membrane Technology for Treating of Waste Nanofluids Coolant: A Review

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**Abstract.** The treatment of waste coolant concerns a great number of industries specially the metal processing industries in order to foster environmental sustainability. Discharging these fluids through a sewer or as a trade effluent is neither a cost-effective or environmentally acceptable waste disposal solution. Several methods for the separation emulsified oils or oily wastewater have been proposed as three common methods, namely chemical, physicochemical and mechanical and membrane technology application. Membranes are used into separate and concentrate the pollutants in oily wastewater through its perm selectivity. Meanwhile, desire to compensate for the shortcomings of the cutting fluids media in metal cutting operation led to introduce the using of nanofluids (NFs) in minimum quantity lubricant (MQL) technique. NFs are nanotechnology-based colloidal dispersion prepared by dispersing nanoparticles (NPs) in conventional liquids, as the base liquid. These advanced fluids have displayed potential to enhance the performance of conventional heat transfer fluids. Investigation of the fabrication and evaluation of physico-chemical, thermo-physical and heat transfer characteristics of NFs for practical heat transfer applications has been studied by few researchers. The use of minimum quantity lubrication (MQL) technique by NFs application is developed in many metal cutting operations. MQL did not only serve as a better alternative to flood cooling during machining operation and also increases better finished surface, reduces impact loads on the environment and fosters environmental sustainability. Waste coolant filtration from cutting tools using membrane was treated by pretreated process, coagulation technique and membrane filtration. Nanomaterials are also applied to modify the membrane structural and morphology. Polyvivylidene fluoride (PVDF) is the better choice in coolant wastewater treatment due to its hydrophobicity. Using of polyamide nanofiltration membranes BM-20D and UF-PS-100-100,000, it was resulted the increase of permeability of waste coolant filtration. Titanium dioxide is nanomaterials additive to modify the nanopores of surface membrane. Contact angle and average pore size were used in investigation of the surface morphology of membranes. An adequate choice in modifying membrane surface in waste coolant filtration may bring a promised alternative as a solution in waste coolant remediation.

## INTRODUCTION

Membrane technology is the most promising filtration for water treatment process in twenty-first Century. Membranes have also become one of the most sought-after techniques in separation processes. They are used in various industries and plants such as desalination, water purification and wastewater treatment plants. The development of science and technology of membrane application is growing rapidly. One of the well-known applications of porous membrane in wastewater treatment is to remove emulsions of different sizes [1]. The method is based on the ability of low pressure to force the dispersed phase to permeate through membrane into a continuous phase and is applicable to both oil-in-water (o/w) and water-in-oil (w/o) emulsions. Large amount of liquid waste in the form o/w or w/o emulsions is generated in the process industries, such as the petrochemical, petroleum, transportation and machining process.

Coolants are essential component of machining process as its cools the cutting zone, lubricates the tool chip contact thereby reducing the friction and temperature generated. Meanwhile, the metal working industries saw the limitation of the use of conventional coolant and coolant strategies. Among the alternative ways of conventional coolant usage reduction, dry machining and minimum quality lubrication (MQL) technique is effective in machining proses in order to foster the sustainability environment. MQL in comparison with flood cooling and dry machining drastically minimize (1/300,000 times) the negative effect on the environment, resulting the reduce of cutting force and usage of coolant [2]. However, the lubricating oil tends to evaporates as it strikes the already heated cutting tool at high temperature. The need of thermal conductivity nanoparticles in cutting fluids are explored to eliminate or reduce drastically the shortcomings of conventional coolants in MQL technique.

Nanofluids (NFs) are new classes of fluids engineered by dispersing nanomaterials in based fluids that could be deionized water, esters or vegetable oils (e.g. coconut oils) [3]. Nanomaterials are defined as the materials whose structural have dimensions in the range between 1 and 100 nanometer. In nanomaterials due to the increase of surface area to the volume, some physical and chemical properties such as thermal, electrical, mechanical, chemical, optical and magnetic property of the materials can be changed significantly. The most important point is that nanomaterials exhibit different and unique properties as compared to the bulk materials with the same compositions [4]. NFs are class of solid/liquid mixtures engineered by dispersing nanoparticles in conventional base liquids. Common nanoparticles could be metallic/intermetallic compounds namely, Ag, Cu, Ni Fe ceramic compounds namely oxides, sulfides, carbides, $Al_2O_3$, $Fe_2O_3$, $TiO_2$, $SiO_2$, $ZnO_2$ are some nanostructured materials [2]. Base liquids are divided as a three phase suspension system selected from water, ethylene glycol (EG), mixture of water and EG (W/EG), diethylene glycol (DEG), polyethylene glycol, engine oil, vegetable oil, paraffin, coconut oil, gear oil, kerosene, and pump oil.[2]. NFs were applied in different areas such as thermal application, fuel additives, lubricant, surface coating, environmental remediation, inkjet printing, biomedical, and petroleum industry. Example of the NFs thermal applications is cooling system in different industries, such as metal cutting operation. Cooling is most potential scientific challenges in different industries for heat transfer applications [5]. NFs can be used in metal cutting and could also be used as efficient coolant in data centers and electronics cooling systems, as shown in Figure 1 [6]. NFs were applied also in environmental remediation as an additive in membrane composition in order to produced nanofiltration membrane.

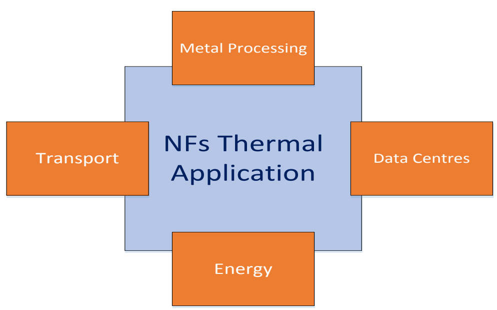


**FIGURE 1.** Nfs Thermal Applications

## MACHINING FOR COOLING AND/OR LUBRICATION

Proper selection of coolants is particularly important as it could affect the tool life, cutting forces, power consumption, machining accuracy, surface integrity etc [7]. Despite the significant effects of coolants in machining process, the selection of the type and delivery system of the coolants are usually based on the recommendations of coolants suppliers and machine tool manufactures. Substances used in machining for cooling and/or lubrication can be defined as cutting fluids, gas-based coolants/lubricants and solid lubricants. It has been used widely accepted characteristics of the coolants is their miscibility in water. Then, it has been used in order to categorize the coolants into water-soluble or non-water soluble, also known as oil-based coolants [8].

Oil-based fluids are one of alternative coolant used in machining operations. They are classified into two basic categories such as naphthenic mineral oils and paraffinic mineral oils. Based on the limitation of mineral oils, some studies develop the use of vegetable oils as coolants in machining operations [8, 9]. Moreover, vegetable oils is classified as nanofluids that potential to enhance the performance of conventional heat transfer fluids. Stability of NFs is one of the key features for any NFs system in each application, especially heat transfer application.

The study of stability of NFs including the key factors which influence the stability as well as the techniques which can be used for the evaluation of the stability of NFs are necessary. Factors affecting stability of NFs was showed in Figure 2, which influence the stability of NFs and based on that to achieve stable NFs, surface modifiers (such as surfactants), pH adjustment, NFs preparation method, mixing/homogenization as well as nanoparticles loading play key role. It should be mentioned that each NFs system needs its particular dispersion method to stabilize the nanoparticles in base liquid to achieve stable suspension.

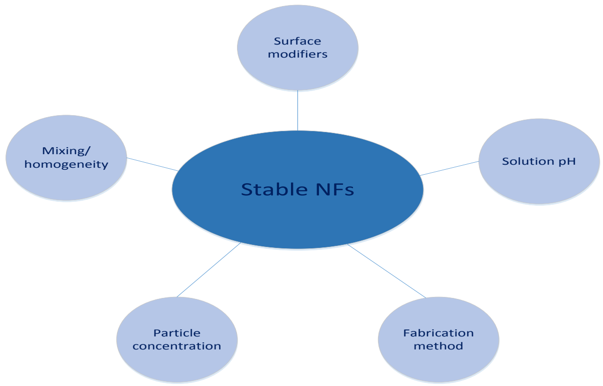


**FIGURE 2.** Factor Affecting Stability of NFs

# MEMBRANE FILTRATION APPLICATION

Membrane filtration is the use of a special porous material manufactured for the interception role in the physical removal of a certain way of the trapped particle size of contaminants. The difference in pressure driven membrane filtration is generally divided into microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). The membrane filtration is characterized by waste oil according to the particle size membrane molecule weight cut off (MWCO) reasonable certainty and the process in general has no phase change, a direct realization of oil-water separator; without pharmaceutical dosing, less pollution; reprocessing costs low, the filtration has less energy consumption; separation of water has low oil content. It needs to be modified the neat membrane to be more effective in filtration process. Membranes will modified with adding the nanoparticles in order to enhance the membrane performance.

## Membrane Classification

MF and UF typically run at low pressure, e.g. <6 bar, but NF and RO runs at relatively high pressure, e.g. >8 bar. Regardless of the membrane pore size, actual solute sizes rejected by MF and UF are approximately same since the cake layer formed on membrane surface acts as a dynamic membrane in actual filtration process. However, tiny molecules with low molecular weight perhaps less than a few tens of thousands Dalton can be better rejected by UF than by MF regardless of the existence of dynamic membrane. NF branes and RO membranes are used to remove trace organic molecules and ions in water filtration. Due to the looser skin layer structure, NF membranes tend to pass mono-valent ions ($Li^+$, $Na^+$, $K^+$, etc.), but not di- and tri-valent ions ($Ca^{2+}$, $Mg^{2+}$, $Fe^{2+}$, $Fe^{3+}$, etc.). Figure. 3 illustrates classification of membrane filtration as a function of molecular weight cut off and pore size.

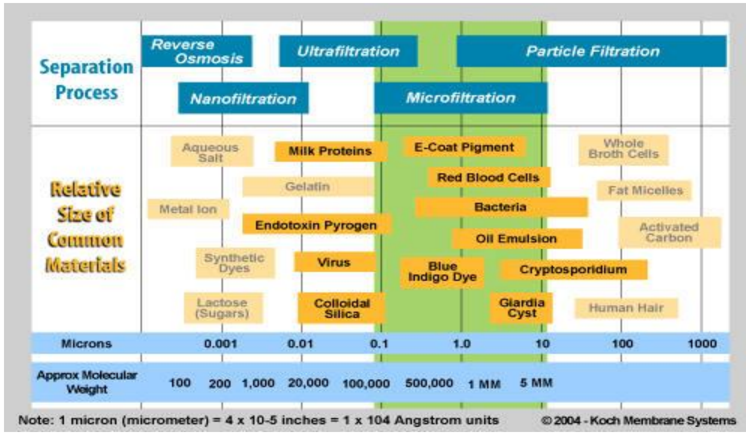


**FIGURE 3.** Classification of membrane filtration as a function of molecular weight cut off and pore size (Koch Membrane Systems).

## Performance Evaluation of Various Membrane Materials for the Coolant Wastewater Treatment

The membrane filtration technology is characterized by waste coolant/waste oil according to the particle size membrane MWCO reasonable certainty. The process has no phase change, a direct realization of oil-water separator without pharmaceutical dosing, so less pollution, reprocessing costs low and has less energy consumption. Yu et al (2006) applied a tubular ultrafiltration (UF) module equipped with polyvinylidene fluoride membranes modified by inorganic Nano-sized alumina particles to purify oily wastewater from an oil field [10]. Results showed that added nanoparticles alumina improved membrane antifouling performance and flux recovery ratio of modified membranes achieved 100% washing with 1 wt..% of OP-10 surfactant solution (pH 10). Zhang et al (2009) applied polysulfone (PSf) to treat oily wastewater [11]. The results revealed that oil retention was 99.16% and oil concentration in the permeation was 0.67 mg/L, which met the requirement for discharge (<10 mg/L). This research has proven that developed composite membrane with adding nanomaterials are reasonably resistant to fouling and hence the modified PSf membranes are considered feasible in treating oily wastewater.

Abadi et al. (2011) prepared a tubular ceramic microfiltration (MF) (α-Al2O3) system for the treatment of typical oily wastewater [12]. The permeate was contained with oil and grease of 4 mg/L that met the National Discharge Standard and exhibited TOC removal efficiency to be higher than 95%. The results showed the best recommended process condition by Trans Membrane Pressure (TMP) of 0.125 MPa, cross flow velocity (CFV) of 2.25 m/s and temperature of 32.5 $^{o}$C. Backwashing was used to remove oil droplets and particulates which blocked the membrane pores and could also prevent flux decline significantly. Mittal et al (2011) employed nanomaterials ceramic-polymeric composite membrane from clay, kaolin and a small amount of binding materials for treating oily wastewater in order to minimize the final cost of composite membrane [13]. This showed that higher pressure and higher initial oil concentration resulted in higher flux decline. The maximum rejection was reached of 93% at 41 min for an initial oil concentration of 200 mg/L at 138 kPa.

Sarfaraz et al. (2012) investigated the possibility of nanoporous membrane powdered activated carbon (NPM-PAC) to treat the oily wastewater [14]. Results demonstrated neat NPM was ineffective in removing total suspended solids (TSS), chemical oxygen demand (COD) and total organic carbon (TOC). The removal of COD and TOC were 62.2% and 75.1% respectively and the steady permeation flux (SPF) was 78.7 L/m2h. Addition of PAC dosage in membrane solution leads a less deposit layer with a high porosity on the membrane surface, which the permeation flux increases up to 133.8 L/m2h and removal of COD and TOC were 78.1% and 90.4% respectively. This was concluded that NPM-PAC hybrid membrane system has the potential method to improve membrane fouling and permeation flux with cross flow filtration system in the desalted plant. Salahi (2013) produced a sheet nanoporous membrane Poly Acrylonitril (PAN) in pore size of 10 nm for treating oily wastewater [15]. The results showed that nanoporous membrane is efficient for treating petroleum refinery wastewater in a desalted plant. TSS, oil and grease content, COD, BOD were increased to 100%, 44.4%, 99.9%, 80.3%, and 76.9%, respectively. Table 1 listed oily wastewater treatment by membrane filtration.

**TABLE 1.** Oily Wastewater Treatment By Membrane Filtration

| Type of membrane | Results | References |
|---|---|---|
| Polyvinylidene fluoride membranes modified by inorganic Nano-sized alumina particles Ultra-filtration | Oil content is below 1 mg/L | Yu et al.(2006) |
| Composite polysulfone (PSf) | Oil retention was 99.16% and oil concentration in the permeation was 0.67 mg/L | Zhang et al (2009) |
| Tubular ceramic micro-filtration (MF) ($\alpha$-$Al_2O_3$) | Oil and grease content of 4 mg/L and exhibited TOC removal efficiency was higher than 95%. | Abadi et al. (2011) |
| Hydrophilic ceramic-polymeric composite membrane | Maximum rejection was reached of 93% at 41 min for an initial oil concentration of 200 mg/L at 138 kPa. | Mittal et al (2011) |
| NPM-PAC nanoporous membrane | COD and TOC removal were 78.1% and 90.4% respectively | Sarfaraz et al. (2012) |
| PAN nanoporous membrane | TSS, oil and grease content, COD, BOD were increased to 100%, 44.4%, 99.9%, 80.3%, and 76.9%, respectively | Salahi et al (2013) |

## EFFECT OF NANOPARTICLES (NPS) ADDITIVES ON MEMBRANE MORPHOLOGY

Polyvinilidene fluoride (PVDF) is a widely used polymer for making porous membrane for oily wastewater teatment. PVDF is a semi-crystalline phase polymer containing a crystalline phase and an amorphous and/or rubbery phase. The crystalline phase provides thermal stability and the amorphous phase has flexibility towards membranes. PVDF is stable while it is attacked by most the corrosive chemicals and organic compounds including acids, alkaline, strong oxidants and halogen. In addition, the hydrophobicity of this polymer provides a potential application in the membrane-based oil/water separation [16]. Composition effect of solvent, additive, and coagulation media was also investigated [17]. In general, large voids were formed when using water as the coagulant, while the voids were reduced when using alcohol and the mixture of water and alcohol or the mixture of water and solvent. Solvent effect on the membrane morphology was investigated by Yuliwati et al. (2010) who employed different solvents including, DMAc and DMF and also different nanoparticles composition as additive in PVDF dope solution [18]. Fontananova et al. [19] studied the effect of nanoparticles of PVP and LiCl in the casting solution on the formation of PVDF membrane. System with a rapid phase inversion rate tends to form macro voids with finger-like structure, whereas systems with a slow phase inversion rate result in a sponge-like structure. LiCl in the PVDF polymer solution works as an agent for suppressing macro void formation (kinetic effect) at high concentration (7.5%), but at a low concentration (2.5%) it operates as a permeate flux enhancer (thermodynamic effect).

Among the mostly used inorganic nanoparticles, nanoparticles titanium dioxide (TiO2) is special interested for its good performance like hydrophilicity, good chemical stability, antibacterial property and could also be used in wastewater treatment [20]. Yang et al [21] showed that as the addition amount of TiO2 nanoparticles increased, cross section changed from macro voids to sponge-like for the increasing viscosity of dope solution. In additional, Cao et al [22] investigated the addition of nanoparticles led to better hydrophilicity and permeation properties. The water contact angle were measured at 250C for drop ages 50-100 seconds about 70 – 850. Table 2 shows values of contact angle and hydraulic permeability of the obtained membranes. The value of contact angle for pure polymers coincide relatively well [23].

**TABLE 2.** Values Of Contact Angle, Hydraulic Permeability and Mean Pore Radii [19-23]

| Membrane | Contact angle Θ | Lhi x 109 (m3/m2 Pa s) | rpm (nm) |
|---|---|---|---|
| PVDF/ Al2O3 | 45 | n.a. | n.a |
| PVDF/ LiClO4/ TiO2 | 40.04 | n.a | n.a |
| PVDF/LiClO4 | 80 | n.a | 50.0 |

**TABLE 2.** Values Of Contact Angle, Hydraulic Permeability and Mean Pore Radii [19-23]

| Membrane | Contact angle Ө | Lhi x 109 (m3/m2 Pa s) | rpm (nm) |
|---|---|---|---|
| PVDF/LiCl | 82 | n.a | 22.5 |
| PVDF/TiO2 | 41.60 | 291.5 (l/ m2h) | 15.0 |

## SUMMARY

Study and develop modified membrane material with nanoparticles additives have been reviewed. Generally, it can be concluded that modified PVDF material with adding the nanoparticles offers many more advantages compared to neat membrane in oily wastewater treatment, especially coolant wastewater filtration. To commission the full scale of PVDF membrane treatment in metal industry, a long-term performance of the system should be carried out along with installation of the pretreatment system prior to nanofiltration for the purpose to minimizing fouling and prolonging membrane life span as well as increasing the efficiency of the overall treatment system. Heterogeneity of coolant effluent has been reported by some researchers because it is made by nature and extend of fouling more difficult to control and predict. Membrane fouling is one of the drawbacks in membrane technology that cannot be prevented but can be minimized. It has been reported that hydrophilicity membranes are more advantages with respect to fouling than hydrophobic membranes. Some researchers were reported the effect of pore-forming hydrophilic additives on the membrane morphology and performance could improve membrane permeability and reduce fouling. This condition distributed to develop further study that needs to be carried out in order to select the additive nanomaterial so that the process can be operated economically and successfully.

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## REFERENCES

1. X.C. Cao, J. Ma, X.H. Shi , Z.J. Ren. Apply. Surf. Sci. Vol. 253 (2006), p. 2003-2010.
2. J. Bush, A. Cruse, W. Marquardt. J. Membr. Sci. Vol. 288 (2007), p. 94-111.
3. C.H. Lu, W. H. Wu, R. B. Kale. J. Hazard. Mat. Vol. 154 (2008), p. 649-654.
4. M.L. Hami, M.A. Al-Hasyimi, M.M. Al-Doori. Desalination Vol. 216 (2007),p. 116-122.
5. E. Fontananova, J.C. Jansen, A. Cristiano, E. Curcio, E. Drioli. Desalination Vol. 192 (2006), p. 190-197.
6. J. Busch, A.Cruse, W. Marquadt. J. Membr. Sci. Vol. 288 (2007),p. 94-111.
7. S. P. Deshmukh, K. Li. J. Membr. Sci. Vol. 150 (1998),p. 75-85.
8. Z. Yuan, X.D. Li. Desalination Vol. 223 (2008),p. 438-447.
9. W. Jing, J. Wu, W. Jin, W. Xing, N. Xu. Desalination. Vol. 191 (2006),p. 219-222.
10. S. L. Yu, Y. Lu, B.X. Chai. Desalination. Vol 196, p.76-83.
11. Y.Q. Zhang, P.Cui, T.D. Du, L.B. Shan, Y.L. Wang. Sep. Purif. Technol. Vol 70 (2009), p.153-159.
12. S.R.H. Abadi, M.R. Sebzari, M. Hernati, F. Rekabdar, T. Mohammadi. Desalination. (2011), p.222-228.
13. P. Mittal, S. Jana, K. Mohanty. Desalination. Vol. 282 (2011), p. 54-62.
14. M.V. Safaraz, E. Ahmadpour, A. Salahi, F. Rekabdar, B. Mirza. Chem. Eng. Res Des. Vol. 90 (2012), p. 1642-1651.
15. A. Salahi, I. Noshadi, R. Badrnezhad, B. Kanjilal, T. Mohammadi. J. Environ. Chem. Eng. http://dx.doi.Org/10.1016/j.jece.2013.04.021.
16. T.H Bae, I.C. Kim, T.M. Tak. J. Membr. Sci. Vol. 275 (2006), p. 1-5.
17. Y.N. Yang, H.X. Zhang, P. Wang, Q.Z. Zheng, J.Li. J.Membr. Sci. Vol. 288 (2007), p. 231-238.
18. E. Yuliwati, A.F. Ismail. Desalination. Vol 273 (2011), p. 226-234.
19. E. Fontananova, J.C. Jansen, A. Cristiano, E. Curcio, E. Drioli. Desalination. Vol 192 (2006), p.190-197.
20. J. Saien, H. Nejati. J. Hazard. Mat. Vol. 148 (2007), p. 491-495.
21. T. Yang, Z.F. Ma, Q.Y. Yang. Desalination. Vol 270. (2011), p.50-56.
22. X. Cao, J. Ma, X. Shi, Z. Ren. Appl. Surf. Sci. Vol. 253 (2006), p. 2003-2010.

23. C. Guo, Y. Pan, S. Yang. Intl. J. Eng. Res. Dev.. Vol. 6(10) (2013), p. 95-97.

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