Improvement Incoloy Alloy 800 Weldability After 10 Years of Service through Solution Annealing and Normalizing Method

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ABSTRACT

Incoloy Alloy 800 is widely utilized in the Outlet Manifold Bottom Header (OMBH) inside the primary reformer at a fertilizer plant. Primary reformers in fertilizer plants usually work at high temperatures and pressures for long periods. In this work, Solution annealing and normalizing method were conducted to improve weldability Incoloy alloy 800 after operating for ten years. Characterization of weldability properties is carried out through dye penetrant, X-ray Fluorescence, hardness, X-Ray Diffraction (XRD), and metallography observation. The annealing and normalizing result show that the weldability of Incoloy Alloy 800 increased, indicating a significant reduction in cracks on the weld zone surface. Microstructure observations revealed that microcrack was not found on the weld joint surface after Solution annealing. The maximum hardness value on the fusion zone was obtained at 187 VHN on normalizing, and minimum hardness was obtained on the nontreatment sample 156.33 VHN.

Keywords: weldability, incoloy alloy 800, annealing, normalizing.

INTRODUCTION

Incoloy alloy 800 is super austenitic stainless steel. Nickel, chromium, and iron are the base metals, with molybdenum, copper, nitrogen, and silicon added as additions. In the petrochemical, chemical process, and power generation industries, Incoloy alloy 800 is commonly utilized in high-temperature applications (Yamawaki, Mito, et al. 1977, Dehmolaei, Shamanian, et al. 2008, Tan, Jiang, et al. 2011). These alloys are recognized for their high strength at high temperatures and high corrosion resistance in extreme conditions (Persaud, Ramamurthy, et al., 2016). Even after prolonged exposure to high temperatures, the alloy can remain stable and maintain its austenitic structure. The alloy also has strong resistance to oxidizing, reducing, and aqueous conditions, as well as exceptional strength.

Incoloy alloy 800 is a solid-solution austenitic alloy with titanium nitrides, titanium carbides, and chromium carbides widespread on microstructure. The nitrides are unaffected by heat treatment since they are stable at temperatures below the melting point. Austenitic alloy is sensitized to intergranular corrosion in specific aggressive environments by being exposed to 540-760°C (Kou 2003, Sahlaoui, Makhlouf, et al. 2004, Tan, Jiang et al. 2011, Gunawan and Arifin 2021). OMBH, which has been operating for ten years under extreme conditions, is certain to have experienced sensitization.

The high chromium concentration in the $M_{23}C_6$ phase decreases chromium content in the area surrounding this chromium-rich deposit due to chromium diffusing considerably more slowly than carbon. The chromium concentration near the grain boundaries drops to below 13%, a critical value for the corrosion-resistant corrosion behavior required (Srinivasan, N. 2021, Sahlaoui, Makhlouf, et al. 2004). Incoloy 800 may experience intergranular corrosion and intergranular stress corrosion cracking in corrosive conditions due to sensitization (Tan, Jiang, et al. 2011, Arifin, Gunawan, et al. 2020).

The primary reformer is a reactor in a fertilizer plant operated at a 600-800 °C temperature and a pressure of 30-40 Kg/cm_2. It has a function as a breakdown of hydrocarbon gas into hydrogen. This process occurs at high temperatures and pressures (Alvino, Lega et al. 2010). One of the essential parts of the primary reformer in fertilizer plants is the Outlet Manifold Bottom Header (OMBH).

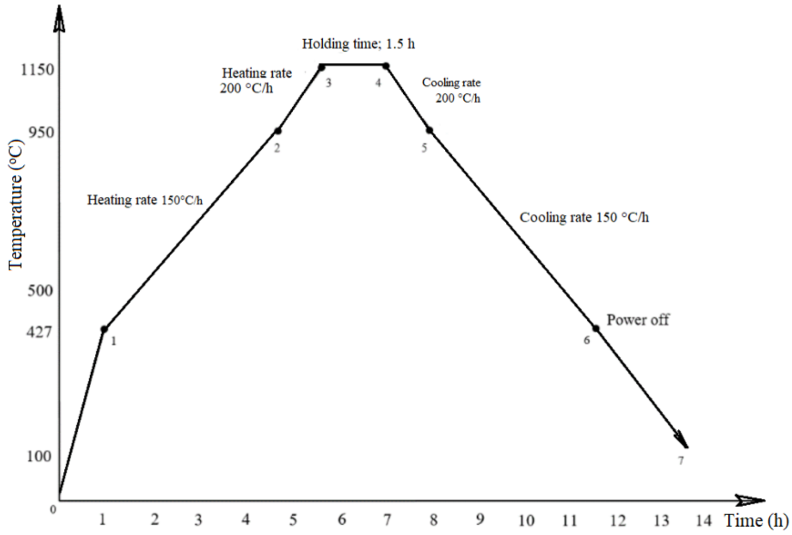
OMBH is manufactured using Incoloy alloy 800 and has been operating for ten years. The OMBH is subjected to high-temperature heat during operation, changing the microstructure and generating residual stress (Tavassoli and Colombe 1978, Karimi, Riffard, et al. 2008).

The purpose of this study was to investigate the weldability properties of Incoloy alloy 800 materials after operating for ten years after the heat treatment process was carried out. Destructive and non-destructive tests were carried out to obtain the data needed to analyze the final result of the heat treatment. These tests include hardness testing, XRF, XRD, penetrant test, weldability test, and metallographic testing using an optical microscope.

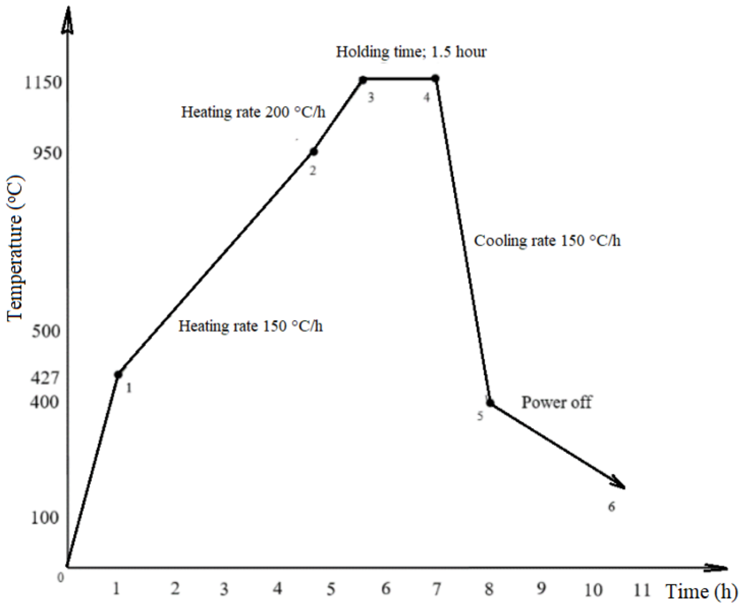
METHODOLOGY

The material used during this research process came from the Outlet Manifold Bottom Header (OMBH) component (Figure 1). It operates at high pressure and temperature categorized as a superalloy type, namely alloy 800, which has resistance to high pressure and temperature and resistance to corrosion. The Incoloy alloy 800 used by a fertilizer plant for the OMBH component produced by Manoir Industries is M900. Furthermore, its composition was investigated through X-Ray Fluorescence Analyzer Niton XL 2. The welding was performed using Gas tungsten arc welding (GTAW) with Filler Rod Er NiCrMo-3. Liquid penetrant testing is conducted before and after welding to reveal open surface welding defects. In this work, the Weldability sample is measured to refer to the effect of welding on indications of defects or crack appearance after the dye penetrant test. A weldability test was performed before and after the welding process. Heat treatment for OMBH was carried out through solution annealing and the normalizing process refer to the Association of Mechanical Engineering (ASME) standards for Incoloy alloy 800 material. A schematic diagram for heat treatment can be shown in Figure 2. The measurement of the hardness value in the weld area was carried out using the Vickers method with a diamond indenter to get better accuracy. Vickers method was performed with load 20 Kgf based on JIS Z 2244 standard with three repetitions. X-Ray Diffraction was conducted on the welding position to investigate phase formation. Furthermore, analysis metallography was conducted using etching fluid (20 ml HNO_3 and 80 ml HCl) and optical microscope, which refers to ASTM E-407 standard.

Figure 1. Outlet Manifold Bottom Header



(a)



(b)

Figure 2. Schematic diagram of the heat treatment process, a) Normalizing and (b) Solution Annealing

RESULTS AND DISCUSSION

XRF results show that the material used in the outlet manifold bottom header (OMBH) is Incoloy alloy 800 type. The chemical composition, as shown in Table 1.

Table 1 Chemical composition of Incoloy alloy 800

Element	Cr%	Ni%	Mn%	Fe%	Nb%
Wt%	20,97	34,30	1,14	42,09	1,21

Table 1 shows that the test results show that the material included in the Incoloy alloy 800 group with the main element is 34Ni-21Cr-42Fe with nickel elements that are more than 25% and chromium more than 14%. These properties can withstand oxidation reactions that cause corrosion at high temperatures. Before the weldability test, visual analysis using dye penetrant was carried out on each sample. Visual analysis observation revealed no indication of defects or cracks on the surface of each sample. No defects or cracks on the surface are indicated by the absence of a red penetrant liquid to the surface after using the developer fluid when finished spraying.

Heat input accompanied by a relatively fast cooling rate in the welding process causes a temperature difference and a cooling difference that results in residual stress (Kou 2003, Lippold and Kotecki 2005). Incoloy Alloy 800 is believed to have relatively high residual stresses due to exposure to heat during operation. The presence of residual stress will trigger cracks proven through dye penetrant testing. Visually indicated defects or cracks are shown in the boundary between the fusion zone and the base metal.

Heat treatment of samples was carried out by solution annealing and normalizing methods that have the main objective of reducing residual stresses to improve the ductility of the alloy 800. Parameters in heat treatment refer to ASME Section VIII Div 1 part UCS-56 and UNF-56.

The results of the annealing solution sample and the normalizing sample after the heat treatment process stated that the normalizing sample indicated that there were still indications of defects or cracks on the surface of the normalizing sample that the welding process had carried out. The indication of defects or cracks in normalizing samples has been significantly reduced, as shown in Figure 3. Defects or cracks can be seen from the results of the penetrant test, which resulted in a red penetrant liquid after the developer fluid spraying process. Weldability test revealed that sample annealing solution showed no indication of defects or cracks after the welding process was carried out on the sample surface.

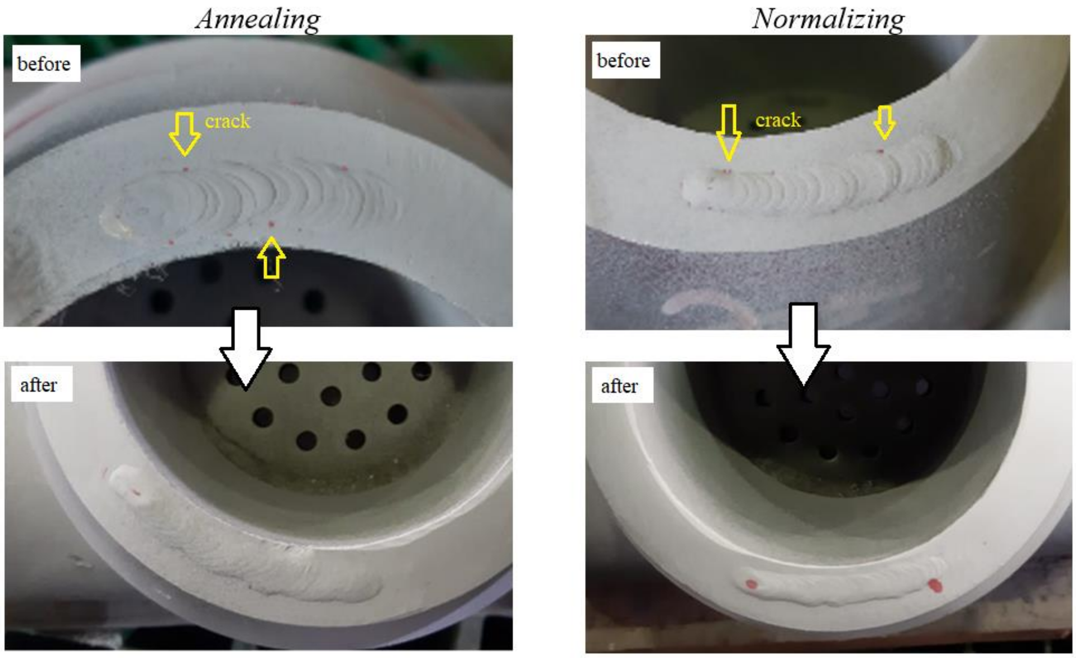


Figure 3. Weldability test before and after heat treatment

Hardness testing is used to measure the resistance of the material to deformation caused by penetration of the surface of a material. The position hardness test of the sample refers to the red line, which can be seen in Figure 4. Incoloy Alloy 800 samples that have been subjected to a weldability test process are then prepared to perform a hardness test by cutting the sample into 2x2 cm sizes and carrying out a framing process derived from a mixture of resin and catalyst.

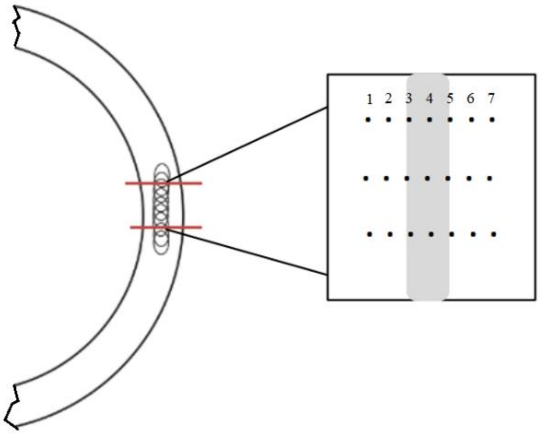
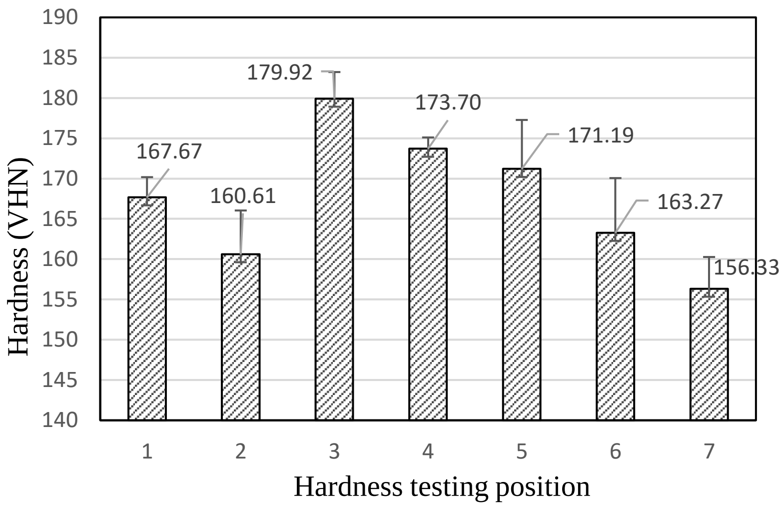
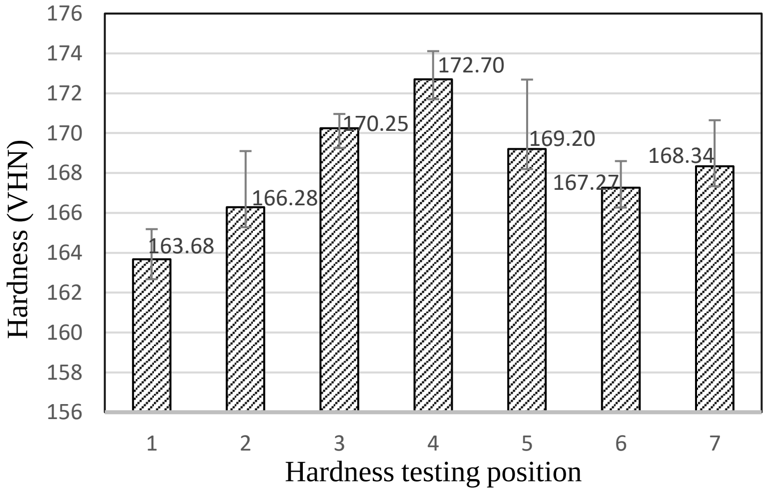


Figure 4 Hardness test position



(a)



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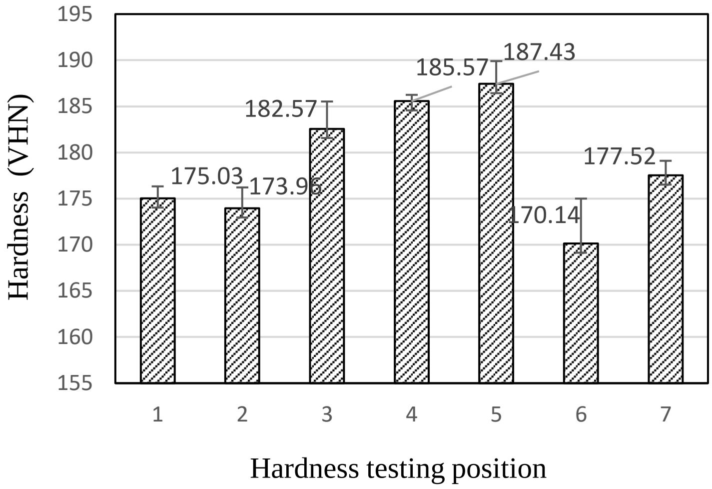

(c)

Figure 5. Hardness profile on weld zone (a) Nontreatment, (b) Solution annealing, and (c) Normalizing

The hardness test results shown in Figure 5 states that the base metal represented by zone 1,2,6 and 7 has decreased hardness from the technical data standard of the alloy 800. The material standard technical data shows the hardness value of the superalloy material with the main element made from nickel and chromium are 170 VHN, while the highest hardness in the base metal is 167 VHN. The low hardness value on the non-treated samples is due to the prolonged exposure to heat during the operation process, as shown in Figure 5 (a). a decrease in the hardness value results in a failure phenomenon such as creep. The hardness value increases in the fusion zone (3,4, and 5) due to new alloys from the filler rod, as shown in Figure 5 (b).

The normalizing sample was machined and polished for preparing the hardness sample test. Furthermore, Hardness testing was carried out seven times at different zone with three repetitions, as shown in Figure 4. Figure 5 (c) shows the hardness testing results on normalizing samples. The test results show that the hardness value of the base metal is close to the Incoloy alloy 800 standard hardness value. The base metal hardness value increased after normalizing treatment if compared to solution annealing and non-treated samples. Due to the slower cooling rate impact, the greatest hardness value on the base metal was reached at 177 VHN during the normalizing process. The preservation of carbide throughout the heat treatment procedure with a slow cooling rate is significant in the resultant growth (Aloraier, A., K. et al 2014, Sharma, N., W. et al 2020). An increase in the amount of carbide plays a role in increasing the hardness value.

The maximum hardness value is 187 VHN in zone 5 on the welding zone. Several variables, such as carbide precipitation and additional alloying elements, influence the hardness value to be high in the welding area. Figure 6 (a) shows the XRD test results from nontreatment samples. The phase characteristics of the alloy material 800, which has been operating for a relatively long time, consist of phases of austenite, $Cr_{23}C_6$, and NbC. The main peaks show the austenite phase with an angle value of 2θ of 43.582 and a peak intensity of 768. An angle value of 2θ of 50.1 indicates the second-highest peak phase with a peak intensity of 368 diffusions (Arifin, Gunawan, et al., 2020). The lowest peak is the diffusion of niobium and carbon, forming NbC carbides with an angle of 2θ of 74.2 and a peak intensity of 90.

Figure 6 (b) shows the XRD test results of the Incoloy alloy 800 heat treatment process with the solution annealing method. The results showed that the phase characteristics consisted of austenite, $Cr_{23}C_6$, and NbC phases. The peak list shown by the graph states that the austenite phase is the peak phase formed with an angle of 2θ of 43.82 and a peak intensity of 279. The second highest peak of the phase is the diffusion between carbon and chromium, which forms $Cr_{23}C_6$ carbide. The diffusion of niobium and carbon owns the lowest peak to form NbC carbides.

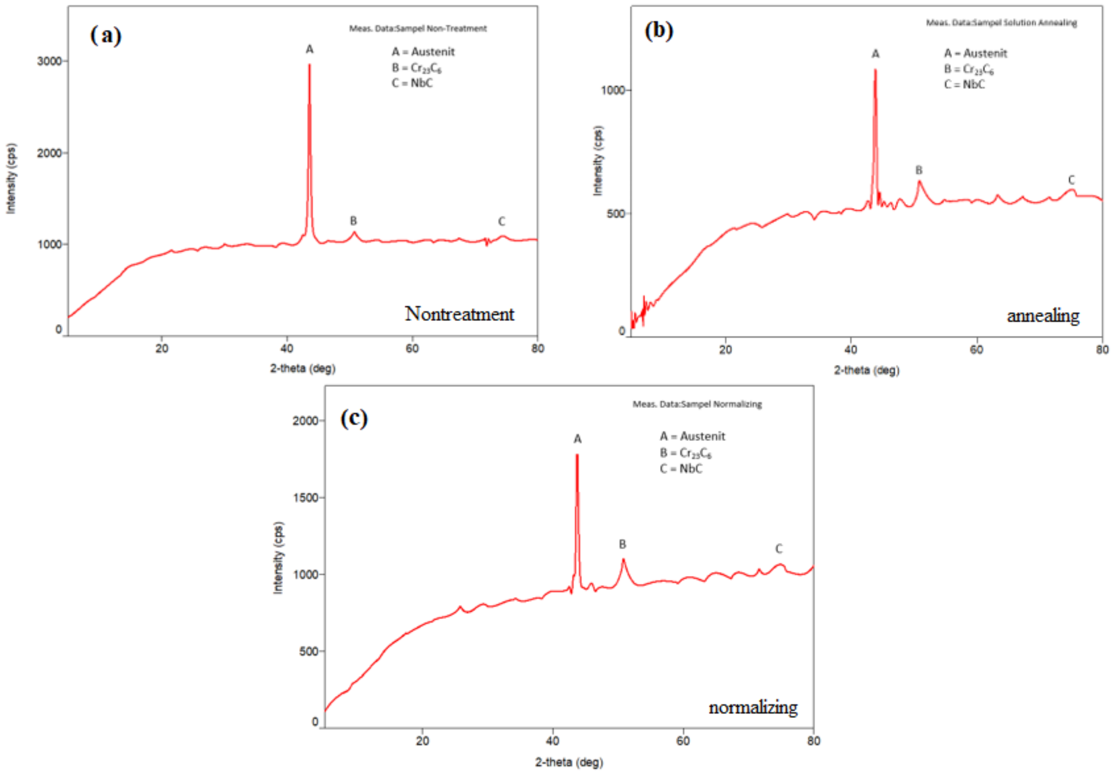

Figure 6. XRD testing results ;(a) nontreatment, (b) annealing, and (c) normalizing sample

XRD test results for Incoloy alloy 800 through the normalizing method can be seen in Figure 6. The results showed that the phase characteristics consisted of austenite, $Cr_{23}C_6$, and NbC phases. The peak list shown by the graph states that the austenite phase is the peak phase formed with an angle of 2θ of 43.82 and a peak intensity of 279. The second highest peak of the phase is the diffusion between carbon and chromium, which forms $Cr_{23}C_6$ carbide. The diffusion of niobium and carbon owns the lowest peak to form NbC carbides.

The XRD test results show almost the same pattern in each trial sample, but the results of the diffraction peak pattern show a widening curve. In the heat-treated sample, the peak shift to 2θ is more significant. Solution annealing samples experienced a significant peak shift than normalizing samples. If material is affected by an inhomogeneous strain field, the peak position shifts and the diffraction peaks are expelled. The peak shift in the XRD result indicates a change in residual stress in each sample due to The effect of strain correlates with the residual stress.

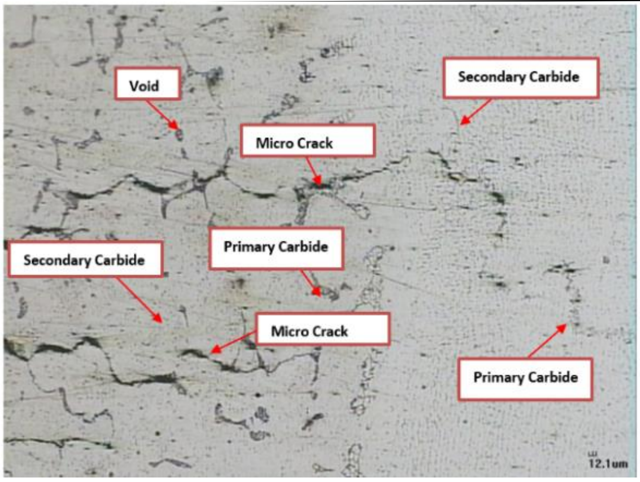

Figure 7. Metallographic testing results of nontreatment sample

The observation result of the nontreatment sample is shown in Figure 7. the microcrack attacks the grain boundaries because there are voids that have fused and are connected. The voids have been spread out in grain boundaries to around grains. Voids can coalesce and be connected due to the influence of residual stress from thermal activity. The microcrack will cause creep cracking on the surface, which causes cracking in the aging Incoloy alloy 800. According to the standard of Manoir Industries, the appearance of microcracks following the weldability test method indicates that the performance of the material has deteriorated. (Anderoglu 2004).

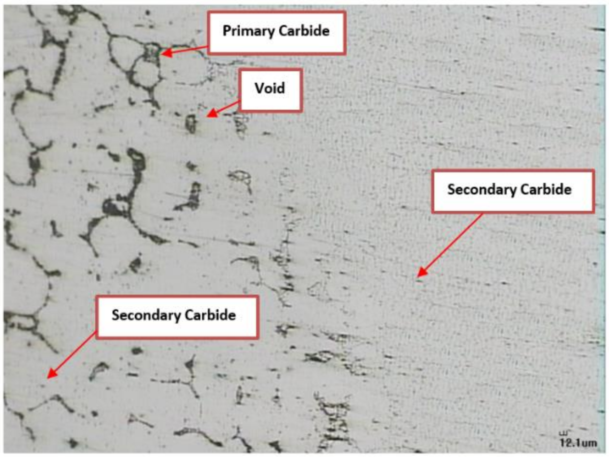

Figure 8. Metallographic testing results of solution annealing sample

The annealing solution sample shown in Figure 8 revealed no microcracks like the non-treated sample. The sample annealing solution indicates the presence of primary carbide, secondary carbide, and voids, but microcrack does not occur in the annealing solution sample. The absence of microcrack is caused by a reduction in residual stress, which minimizes the formation of connected and unified voids.

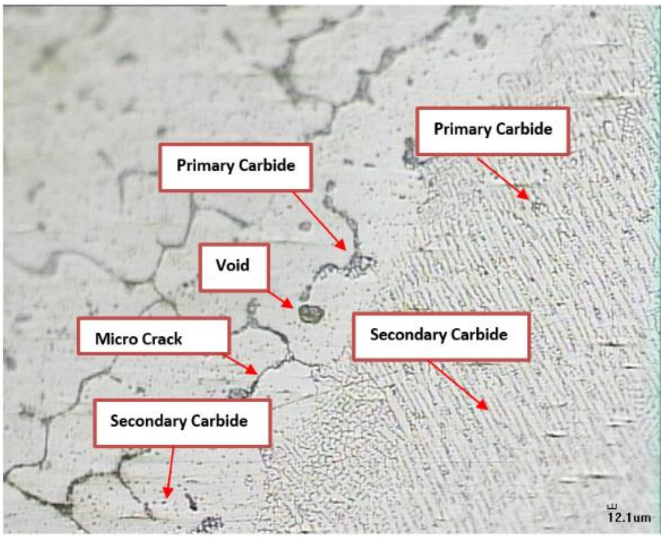

Figure 9. Metallographic testing results of normalizing sample

The normalizing sample is shown in Figure 9 states that there are microcracks that have spread to the boundaries of the weld area. Micro crack propagation occurs due to the influence of heat on the weldability test process. The reduction in residual stress also occurred in the normalizing samples, which was shown in the microcrack formation results that were not as large as the nontreatment samples. The heat treatment minimizes residual stress that can affect voids so that voids do not coalesce and coalesce to form a microcrack.

CONCLUSIONS

Heat treatments for improving weldability Incoloy alloy 800 have been performed successfully. Experimental results show that heat treatment with solution annealing and normalizing methods affects the microstructure and mechanical properties. Solution annealing and normalizing are effective to improve weldability Incoloy alloy 800. Solution annealing sample revealed no crack was observed after the weldability test. On normalizing samples, some cracks after normalizing were still observed. However, the reduction crack on normalizing samples is more significant than before heat treatment. On the non-treated samples, Microstructure observation showed microcracks spread from the base metal to the fusion zone. Microcrack propagation was only found in the base metal in the normalizing sample. The microcrack occurs due to the residual stress effect on the voids formed due to the influence of carbide precipitation. The hardness test results showed that each sample experienced an increase in the highest hardness value in the fusion zone caused by new alloy elements from the filler rod and residual stress.

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