REGISTRATION

	EARLY BIRD (USD) Last Date 30 June 2017	NORMAL (USD) Last Date 30 July 2017	PUBLICATION FEE (USD)	
			Scopus Journal	Scopus Proceeding
International Participant	200	250	150	75
International Student	150	175	150	75
Additional Paper International	100	125	150	75
Local Participant	100	150	150	75
Local Student	100	125	150	75
Additional Paper Local	50	75	150	75
Listener Local and International	50	75	150	75

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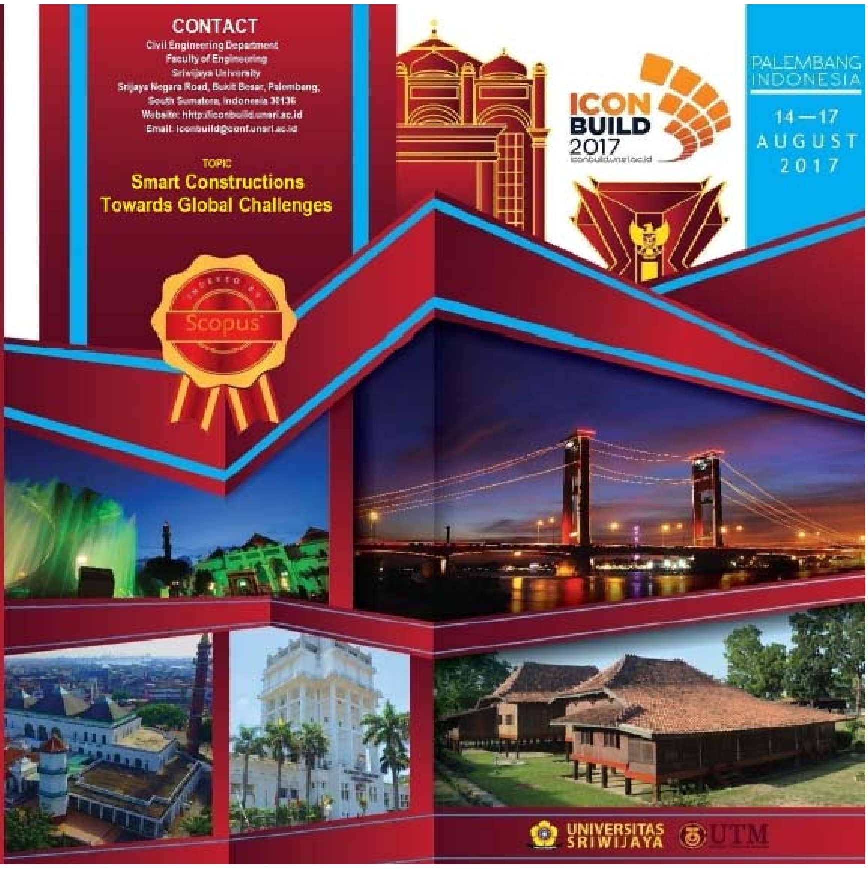

ORGANIZING COMMITTEE
INTERNATIONAL CONFERENCE ON CONSTRUCTION AND BUILDING ENGINEERING [ICONBUILD 2017]
Palembang, August 14-17, 2017

Invoice No: SCE-051/P/ICONBUILD2017

Date: 31th July 2017

Hasan Basri,
Mechanical Engineering Department, Faculty of Engineering, Universitas Sriwijaya, Inderalaya, Indonesia

No	Description	Amount
1	**Publication Fee: The Third International Conference on Construction and Building Engineering – ICONBUILD2017** **14-17 August 2017, Palembang, Indonesia** ❖ Paper ID: SCE-051 ❖ The Study of Fatigue Crack Initiation in the Rotary Cement Kiln under Cyclic Loading using Non-Linear Finite Element Method ❖ For payment: Publication Fee (IJASEIT (International Journal on Advanced Science, Engineering and Information Technology))	USD 150.00

Total: USD 150.00

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2	08.15 - 08.30	SCE-048	Behavior of Rubber Base Isolatator with Various Shape Factors	Tavio, Hidajat Sugihardjo, Agung Purniawan, and Yudha Lesmana	Department of Civil Engineering, Sepuluh Nopember Institute of Technology (ITS), Surabaya, Indonesia
3	08.30 - 08.45	SCE-049	Experimental study on the strength of double shear timber connection using bamboo dowel fastener	Buan Anshari, Wayan Sugiartha, Fathmah Mahmud, and Pathurahman	Department of Civil Engineering, Faculty of Engineering, Mataram University, Jl Majapahit 62 Mataram, NTB, Indonesia
4	08.45 - 09.00	SCE-050	Behavior of Modified Long Links with Supplemental Double Stiffeners on Eccentrically Braced Frames	Musbar, Bambang Budiono, Dyah Kusumastuti and Herlien D. Setio	Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Ganesa 10, 40132 Bandung, Indonesia
5	09.00 - 09.15	SCE-051	The Study of Fatigue Crack Initiation in the Rotary Cement Kiln under Cyclic Loading using Non-Linear Finite Element Method	Hasan Basri, Irsyadi Yani, Jimmy D. Nasution, Akbar Teguh Prakoso	Mechanical Engineering Department, Faculty of Engineering, Universitas Sriwijaya, Inderalaya, Indonesia
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(SCE-050)
Behavior of Modified Long Links with Supplemental Double Stiffeners on Eccentrically Braced Frames

Musbar*, Bambang Budiono, Dyah Kusumastutiand Herlien D. Setio

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*Corresponding email: musbar.ibrahim@gmail.com

Initial failure of long links caused by fracturing and buckling occurs on the flange and web at the end of the link. Local damages are caused by the influence of the dominant bending moments compared to shear forces. The advantage of using long links includes allowing for larger openings in rooms, which makes it popular among architects. Efforts to prevent these specific failures are not covered in the rules and there are few researches that examine improving the performance of long links. The focus of this study is to provide information on using supplemental double stiffeners on both sides of the web at the ends of the long link without changing the long link behavior. The behavior of long links is maintained by keeping the flange failures on the flange at the end of the link. The supplemental double stiffeners improves the performance of the long link by extending the inelastic zone and slowing the failure rate of the flange. This experimental study was carried out on four models of the long link consisting of a standard model and a model modified by the addition of supplemental double stiffeners at the flange. Long link models were modified with variable thickness and holes width on the supplemental double stiffeners. The results showed that the addition of the supplemental double stiffeners can improve the performance of long links compared to the standard link that is in accordance with the requirements of AISC 341-10.

(SCE-051)
The Study of Fatigue Crack Initiation in the Rotary Cement Kiln under Cyclic Loading using Non-Linear Finite Element Method

Hasan Basri*, Irsyadi Yani, Jimmy D. Nasution, and Akbar Teguh Prakoso
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This paper proposes an in-situ fatigue-crack assessment of the cement rotary kiln shell that is fabricated with elements of steel base plates with the specification of ASTM A516 grade 70. The objective of this research is to obtain the fatigue life and crack initiation within the kiln shell using the method of strain-based fatigue analysis with the low cyclic stress from loading condition. This can be achieved by using the non-linear finite element analysis (FEA) that is conducted to obtain simulation for predicting service life and damage regions on certain location where cracks are initiated. Therefore, FEA is started by using the data from the preliminary stress analysis based on the non-linear static study of the shell. The 3D solid model of the shell is converted into solid meshed FEA model detailed with the weldments between steel base plates using the specified connector feature. Applying the S-N data of steel fatigue properties from previous experiments, the fatigue study will run after defining the loading scenario based on static analysis result demonstrating the stress distribution and factor of safety within the kiln shell structure. By post-processing FEA, the fatigue life of the shell structure is predicted, referring to the minimum stress cycles of 2.992 x 102 times. The certain location with damage percentage of 100% or greater are carefully observed to indicate the regions of crack initiation. Obviously, the equivalent plastic strain range is the dominant parameter of the mixed mode fatigue crack growth, and stress is dominant for fatigue crack growth.

(SCE-052)
Analysis of Offshore Platforms Lifting with Fixed Pile Structure Type (Fixed Platform) Based On ASD89

Agus Sugianto* and Andi Marini Indriani

Civil Engineering Departement, Faculty of Engineering Balikpapan University, Balikpapan, Indonesia
*Corresponding email:agus.fadhil@yahoo.co.id

Platform construction GTS (Gathering Testing Sattelite) is offshore construction platform with fix pile structure type/fixed platform functioning to support the mining of petroleum exploitation. After construction fabrication process platform was moved to barges, then shipped to the installation site. Moving process is generally done by pull or push based on construction design determined when planning. But at the time of lifting equipment/cranes available in the work area then the moving process can be done by lifting so that moving activity can be implemented more quickly of work. This analysis investigates moving process of GTS platform in a different way that is generally done to GTS platform types by lifting using problem is construction reinforcement required so the construction can be moved by lifting with analyzing and checking structure working stress that occurs due to construction moving process by lifting AISC code standard and analysis using the SAP2000 structure analysis program. The analysis result showed that existing condition cannot be moved by lifting because the produced stress ratio is above maximum allowable value that is 0.950 (AISC-ASD89) . Overstress occurs on the member 295 and 324 with stress ratio value 0.977 and 0.955 so that it is required structural reinforcement. Box plate application at both members so that it produces stress ratio values 0.78 at the member 295 and stress ratio of 0.77 at the member 324. These results indicate that the construction have qualified structural reinforcement for being moved by lifting.

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The Study of Fatigue Crack Initiation in the Rotary Cement Kiln under Cyclic Loading using Non-Linear Finite Element Method

Hasan Basri[1, a)], Irsyadi Yani[1], Jimmy D. Nasution[1], Akbar Teguh Prakoso[1]

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Abstract. This paper proposes an in-situ fatigue-crack assessment of the cement rotary kiln shell that is fabricated with weldments of steel base plates with the specification of ASTM A516 grade 70. The objective of this research is to obtain the fatigue life and crack initiation within the kiln shell using the method of strain-based fatigue analysis with the low cyclic stress from loading condition. This can be achieved by using the non-linear finite element analysis (FEA) that is conducted to obtain simulation for predicting service life and damage regions on certain location where cracks are initiated. Therefore, FEA is started by using the data from the preliminary stress analysis based on the non-linear static study of the shell. The 3D solid model of the shell is converted into solid meshed FEA model detailed with the weldments between steel base plates using the specified connector feature. Applying the S-N data of steel fatigue properties from previous experiments, the fatigue study will run after defining the loading scenario based on static analysis result demonstrating the stress distribution and factor of safety within the kiln shell structure. By post-processing FEA, the fatigue life of the shell structure is predicted, referring to the minimum stress cycles of 2.992 x 10^2 times. The certain location with damage percentage of 100% or greater are carefully observed to indicate the regions of crack initiation. Obviously, the equivalent plastic strain range is the dominant parameter of the mixed mode fatigue crack growth, and stress is dominant for fatigue crack growth.

Keywords: Fatigue life, rotary kiln shell, low cyclic stress, finite element analysis.

1. INTRODUCTION

Cement kilns are used for the pyro-processing stage of manufacture of Portland and other types of hydraulic cement, in which calcium carbonate reacts with silica-bearing minerals to form a mixture of calcium silicates. Over a billion tonnes of cement are made per year, and cement kilns are the heart of this production process: their capacity usually defines the capacity of the cement plant. As the main energy-consuming and greenhouse-gas–emitting stage of cement manufacture, improvement of kiln efficiency has been the central concern of cement manufacturing technology.

In the safety assessment of the cement plant, the fatigue crack growth behaviour on the rotary cement kiln should be evaluated. Rotary kiln shell is welded by cylindrical steel plates. The rotary kiln consists of a tube made from steel plate, and lined with firebrick. The tube slopes slightly (1–4°) and slowly rotates on its axis at between 30 and 250 revolutions per hour. Raw mix is fed in at the upper end, and the rotation of the kiln causes it gradually to move downhill to the other end of the kiln. At the other end fuel, in the form of gas, oil, or pulverized solid fuel, is blown in through the "burner pipe", producing a large concentric flame in the lower part of the kiln tube. As material moves under the flame, it reaches its peak temperature, before dropping out of the kiln tube into the cooler. Air is drawn first through the cooler and then through the kiln for combustion of the fuel. In the cooler the air is heated by the cooling clinker, so that it may be 400 to 800 °C before it enters the kiln, thus causing intense and rapid combustion of the fuel (see Fig. 1).

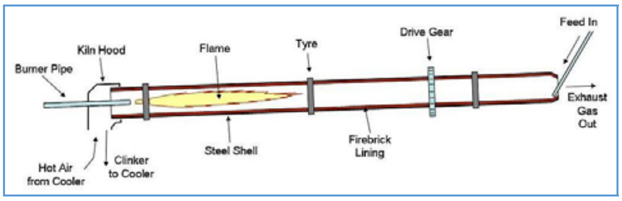


Fig. 1. Fundamentals of cement rotary kiln

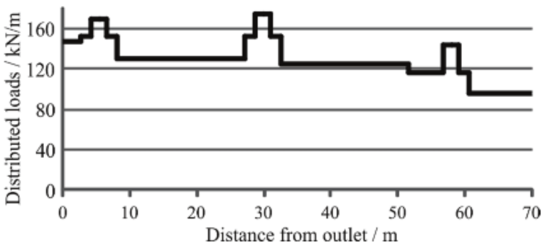
The total mass of the rotary kiln shell is around 55.92 tons and is supported by three ring-roller stations, spaced along the length of the kiln. The main dimensions and properties of the kiln necessary for subsequent analysis are given in Table 1.

Crack propagation of weld toes near supporting rollers until the final fracture is the main failure form. Padded plates are directly soldered to the shell in the supporting rollers places to reduce their concentrated stress. Based on fracture mechanics, an overall intensity factor with regard to circumferential stress, concentrated stress, residual stress, and temperature stress is used to asses the crack growth Cracks are often initiated at these welded joints, and the overlong circumferential cracks are prevailing at weld joints near the supporting roles. Cracks can grow with complex overloading conditions for over thousands of tons, and then result in premature shell failure. The effecting conditions for crack growth include material characteristics, initial crack size, and service stresses. FEA can predict stress concentration areas, and can help design engineers predict how long their designs are likely to last before experiencing the onset of fatigue. The mechanism of fatigue can be broken down into three interrelated processes: (1). Crack initiation, (2). Crack propagation, (3). Fracture, (4). Fits together. In this paper, the low cycle fatigue crack growth is studied.

Table 1. Rotary kiln data (in mm)

Ring	Inner radius, R_1	Outer radius, R_2	Width, B
Ring 1	2318	2700	750
Ring 2, 3	2323	2700	880

Distributed loads along the kiln length:



Tanaka et al. **[4]** showed that the mixed mode crack growth occurs in the aluminium alloy specimen under low cycle fatigue condition. The same phenomena were reported by Otsuka et al. **[5]**. By these studies, the condition of the stress intensity factor and the stress ratio of the cyclic loading are proposed for the mixed mode fatigue crack growth. Under low cycle fatigue condition, usually plastic deformation occurs at the crack tip. Then the stress and strain fields around the crack tip becomes very much complicated. By this reason, retailed numerical simulation has not been conducted for this problem, and the mechanical condition for the mixed mode crack growth is not yet clear. However, many of the previous studies only investigated the spatial and temporal patterns of fatigue life variability through modelling and observational analyses, which provided only a partial view of fatigue crack and their relationship to crack growth and stress initiation.

The study of fatigue kiln shell has been discussed in previous research. H. Basri et al. **[6]** investigated the area of vibration with high displacement and fatigue life of the crack growth analysis in a rotary cement kiln using FEM. From the simulation, model and boundary conditions are defined. Crack growth behavior in rotary kiln was predicted. As the crack grows, the speed of the crack depth increase. However, the fatigue damage model for durability assessment of shell kiln has not been fully understood.

Future work, therefore, is directed to predict and analysis the fatigue crack processes and mechanism of the crack growth on the rotary cement kiln that which should make possible fatigue crack estimation on the (1) welded shell, (2) body shell due to thermal stress and loading, and (3) corrosion body shell. A certain extent good lifetime results are obtained compared with practical observation. This paper presents a reasonable procedure to evaluate the propagation lifetime of weld shell, and the results are quite significant for equipment daily maintenance of rotary kiln.

2. FATIGUE STUDY FUNDAMENTALS

2.1. Method of Analysis Approach

Fatigue analysis approaches are categorized into three models (see Fig. 2.):

1. Stress-Based Method.
2. Strain-Based Method.
3. Fatigue Crack Method.

Stress-based approach is useful when the range of stress is not high and due to these reason long lives (more than 10^4 cycles) for components will be expected. In addition, stresses will not exceed than yield strength so and elastic region.

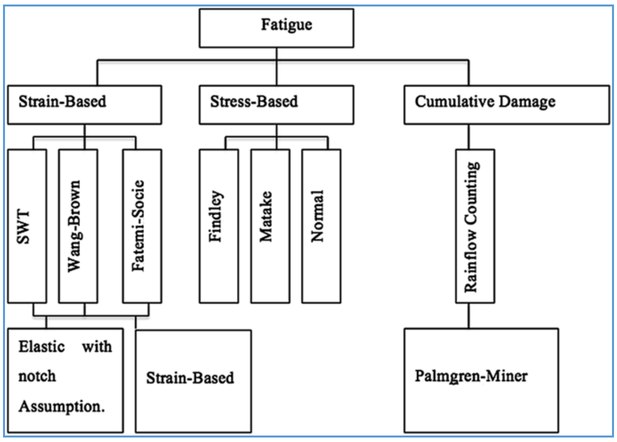


Fig. 2. Fatigue analysis approaches

Strain-based approach is applicable for a structure under low-cyclic loading with high stress amplitude causing the material to yield toward the plastic region. Followed by the crack initiation and growth, consequently, the fatigue life of rotary kiln will decrease. Therefore, the analytical approach to the fatigue study of rotary kiln with cyclic loading will use the strain-based method. Furthermore, stress localization due to stress concentration factor will be expected. In fact, in such problems strain can be measured and this quantity would be excellent quantity for correlating of low cycle fatigue. The local strains can be well above the yield strains in such problems and it would be difficult to measure stresses rather than measuring strain.

2.2. FEA based Analysis and Simulation of Fatigue

The definition of fatigue, in fact, is: failure under a repeated or otherwise varying load, which never reaches a level sufficient to cause failure in a single application.

Finite element method is a numerical method that can be used for solving engineering problems. It is also applicable more for complex geometries combined with loading and various boundary conditions in the sense of different physics analysis, such as stress, fatigue, fluid, and thermal analysis. In this study, finite element method is applied to analyze the fatigue behavior of the rotary kiln.

The symptoms of fatigue are cracks that result from plastic deformation in localized areas. Such deformation usually results from stress concentration sites on the surface of a component, or a pre-existing, virtually undetectable, defect on or just below the surface. While it may be difficult or even impossible to model such defects in finite element analysis (FEA), variability in materials is a constant, and small defects are very likely to exist.

2.3. Mechanical Consideration of the Rotary Kiln

2.3.1. The Kiln Shell

The shell of the kiln is made of mild steel plate. Mild steel is the only viable material for the purpose, but presents the problem that the maximum temperature of the feed inside the kiln is over 1400°C, while the gas temperatures reach 1900°C. The melting point of mild steel is around 1300°C, and it starts to weaken at 480°C, so considerable effort is required to protect the shell from overheating. Historically, the construction of rotary kiln shells has closely paralleled to the construction of boilers.

Shell sections were made from the flat rolled plate, of thickness typically in the range 18-25 mm. The plate was cold-rolled to the required curvature, typically in semi-circular pieces. Two of these were then joined to make a cylinder, usually of length about equal to the diameter. The pieces were butt-jointed welding. The cylindrical sections were joined end-to-end in a similar manner. Short sections were usually assembled at the factory, and final assembly was performed on site, with the kiln in place.

2.3.2. The Kiln Drive, Tyres and Rollers

Ever since the first rotary kilns until recently were turned by means of a single girth gear (known as the turning gear) surrounding the kiln. The early kilns turned very slowly, the girth gear meshing with a worm gear. Subsequently, full-speed rotation of kilns in the range 0.5-1.5 rpm became standard, and the gear meshed with a pinion running at 10-20 rpm. The pinion shaft was driven by a gearbox (see Fig. 3).

The purpose of tyres and rollers is to support the kiln and allow it to rotate with minimal friction as shown in Fig. 3. Rotary kilns are among the largest items of permanently moving industrial machinery, the largest examples weighing in their fully-loaded from several thousand tonnes. Despite the challenges of their size and their high temperature, the best examples of rotary kiln rotate on their rollers almost frictionless, the power supplied by the drive being almost entirely in order to oppose the eccentric load of the contents of the kiln.

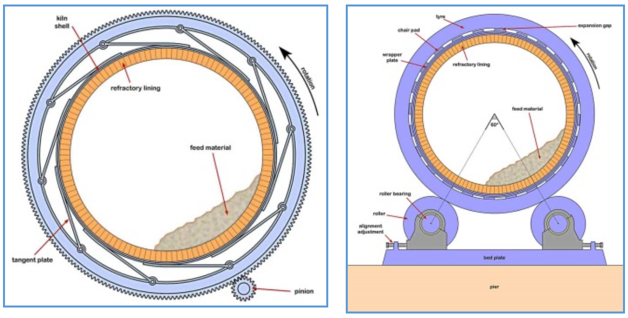


Fig. 3. The Kiln Drive, Tyres, and Rollers

3. METHOD OF FATIGUE STUDY ANALYSIS AND SIMULATION

Fatigue evaluation might be considered by numerical analysis of 3D model of the rotary kiln. By using FEM based on strain accumulation analysis, the fatigue life prediction of the rotary kiln also can be estimated by investigating the crack initiation-growth and its location. In the beginning of finite element analysis (FEA), structural stress analysis on a meshed model of the rotary kiln structure idealized from its 3D CAD must be done first, before the fatigue evaluation is conducted. Based on one of three types of fatigue analysis approaches, the FEA will provide the results and a simulation of fatigue behavior of the rotary kiln. Therefore, the fatigue life can be predicted based on the results. In the following step, procedure of numerical analysis using FEM will be described completely.

3.1. FEA Fatigue Study Procedures

In FEA of SolidWorks Simulation Professional, there is a standard operating procedure to setup a fatigue study. Below are the five primary steps to complete a successful analysis:

Step 1. Determining load type during study creation

There are two types of loading available when defining a fatigue study: constant amplitude and variable amplitude events. When defining a fatigue study, there are two options at the bottom of the new study dialogue window to choose from. One is for defining a constant amplitude fatigue study and the other is for defining a variable amplitude fatigue study. All cycles of a constant amplitude event have the same alternating and mean stresses. A constant amplitude event is fully defined by an alternating stress, mean stress and the number of cycles. A fatigue event can refer to one of more static studies (linear and nonlinear), or to a particular solution step from nonlinear or modal time history dynamic studies. The software calculates the worst alternating stress levels for each event. A variable amplitude event is a load history record that defines the fluctuation history of a load.

Alternating stress (Fig. 4d) is created by the three principal stresses:

- Bending stress, which alternates four times from positive to negative value (Fig. 4a),

- Contact stress, which is negative (Fig. 4b),
- Thermal stress, caused by linear temperature gradient along the section height (Fig. 4c).

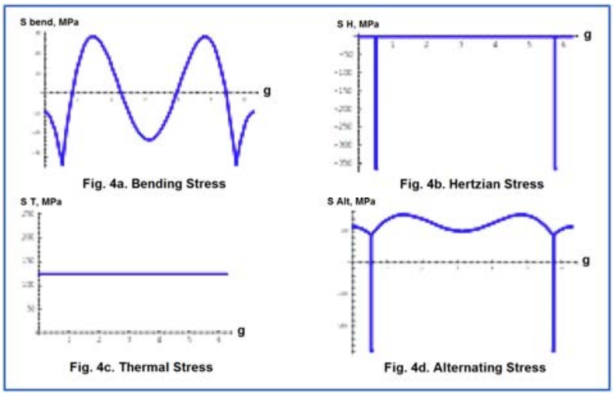


Fig. 4. Alternating stress

The alternating reference stress provides valuable information about fatigue load to which riding ring is subjected. During one revolution the stress alternates four times of tension to compression. As ring has 2 revolutions per minute, this means that during one year the ring has 4.204.800 cycles, if short breakages are neglected. According to S-N diagram, the infinite strength of steel begins at approximately 10 million cycles, corresponding to fatigue strength of application.

Step 2. Adding events for constant amplitude

Input the number of cycles for the event (i.e. 1,000,000 cycles). Specify the loading type (Fully Reversed, Zero Based, Loading Ratio and Find Cycle Peaks). Select the reference studies to tie to the event. A fully reversed load would be an application where a load is fully reversed for a set number of cycles (i.e. a 1000 lbs force load in the X direction is oscillating between the positive and negative X direction. Essentially, the software changes the value of the load from positive to negative for a single cycle and the analysis is run for a set number of cycles). The loading ratio for a fully reversed load is -1. Loading ratio is defined as the minimum load divided by the maximum load. This event is based on one reference study. A zero based load would be one where a load is varied between zero and the value of the load (i.e. from 0 to 1000 lbs). Another way of stating this would be to call it an on/off load. The loading ratio for this scenario is 0. This event is based on one reference study. The loading ratio option allows one to specify a user defined loading ratio (i.e. a scenario where the event is not fully reversed or zero based). If the load cycle oscillates between -5 lbs to +100 lbs, then the loading ratio would be -0.05 (-5lbs/+100 lbs). This event is based on one reference study. The find cycle peaks event type is based on multiple reference studies. The program uses the stress results of the specified studies to find cycle peaks that give the highest alternating stress for each mesh node. An example of this would be if you are evaluating a scenario where a dead load is present (i.e. non-oscillating).

Step 3. Defining the fatigue data

The software uses an S-N curve to evaluate the fatigue results. The S-N curve defines the alternating stress values versus the number of cycles to failure at a given stress ratio. When defining the reference studies, one can specify a material that has fatigue data already inputted for the material. In the SolidWorks material database, the materials that have "SN" appended to the name already have an S-N curve defined. For these materials, the S-N curve is based on a fully reversed load (i.e. the stress ratio is -1). If the referenced studies do not have S-N data tied to their materials, then one can manually input this data. It is possible to apply up to ten S-N curves calculated empirically for different stress ratios. This is important when mean stress needs to be calculated correctly. Lastly, if one is using an ASME Austenitic Steel or an ASME Carbon Steel, then the software can derive the S-N curve from known ASME S-N data. The results of a fatigue analysis are highly dependent on the quality of the input S-N curves.

Step 4. Defining result options, and defining fatigue study properties

Fatigue calculations can be run for the whole model (default option) or surface only. Constant amplitude study options include how to define constant amplitude event interaction, how to compute alternating stress and how to take into account mean stress (mean stress correction type) when there are not enough defined S-N curves to accurately account for mean stress. Variable amplitude study options include defining the number of bins for rainflow counting as well as the alternating stress and mean stress options.

Step 5. Running the analysis and post-processing the results

A fatigue analysis runs very quickly. The reference studies are not rerun. Three plots are available to help evaluate the results of the analysis (life, damage and factor of safety). The life plot depicts the number of cycles that causes failure at a model location (i.e. mesh node point). The life plot is only available when a single event is defined for the analysis. The damage plot depicts the percentage of damage at a model location. A value of 1 indicates that the defined fatigue event consumes 100 percent of the model life at that location. The factor of safety plot is very similar to the factor of safety plot for static analysis. A factor of safety of 2 at a model location predicts fatigue failure at that location when the applied loads are multiplied by 2.

3.2. Technical Data for FEA Analysis

The main geometrical characteristics of the rotary kiln shell are shown in Table 2 and the thicknesses of the shells along the different sections of the rotary kiln are given in Table 3.

Table 2. The main geometrical characteristics

Magnitude	Value	Units
Cold real length	75	meters
Inner diameter	4.5	eters
Number of tyres	3	--
Slope	3.5	%

Table 3. Thicknesses variation of the shell sections

Section (mm)	Thickness (mm)	Section (mm)	Thickness (mm)
0–10,300	25	42,900–45,100	60
10,300–11,900	40	45,100–46,900	40
11,900–14,100	60	46,900–65,300	28
14,100–19,700	40	65,300–66,900	40
19,700–41,100	28	66,900–69,500	70
41,100–42,900	40	69,500–72,500	90
		72,500–75,000	60

In Table 3 zero is placed in the upper end of the rotary kiln, called 'Inlet-I'. The distances between supports, in millimeters, are given in Table 4 where 'III-Outlet' denotes the lower end of the rotary kiln. The rotary kiln along with the structural elements to rotate the kilns and around its longitudinal axis is shown in Tables 3, 4 and Fig. 5.

Table 4. Distances between supports

Supports	Distance (mm)
Inlet–I	13,000
I–II	31,000
II–III	27,000
III–Outlet	4,000

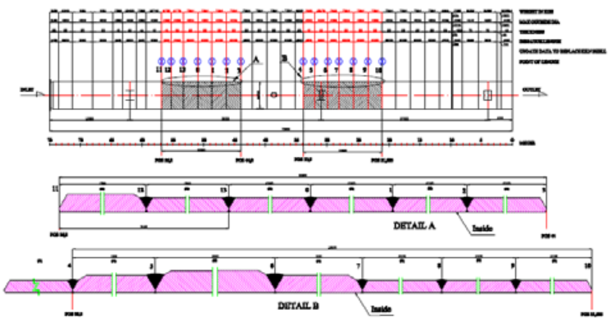


Fig. 5. Diameter, length, and thickness variation of rotary kiln

The kiln includes an elongated, cylindrical, rotating shell which has a feed end, an opposite discharge end, a burner pipe. The kiln is erected so that the discharge end is at a lower level than the feed end in order to cause the material being processed. It travels through the open processing zone to the discharge end. The kiln shell is supported by riding rings or tyres that engage steel rollers, which are supported on concrete piers and steel frames. Materials used for the kiln are shown in Table 5.

These materials are used to build the kiln components. The shell, tyre, roller and pinion are the main components in the kiln. However, the material has been modeled as isotropic and linear, elastic temperature dependent, according to the elastic properties of the steel used in Table 6.

Table 5. Material designation of kiln components

Component	Material Specification
Shells	ASTM 526 Grade 70 or SS 400
Tyres Cast iron	GS-25 Mo.25
Rollers Cast iron	GS-42 Cr Mo.5
Pinion	30 Cr Ni Mo 8 (ISO R 638 = II-68 Type 3)

Table 6. Material specification of ASTM 516 Grade 70

No	Specification of ASTM 516 Grade 70	Grade
1.	Tensile strength	485 MPa
2.	Yield strength	260 MPa
3.	Density	7.85 gr/cm^3
4.	Poisson ratio	0.29
5.	Modulus of elasticity	200 GPa

4. RESULTS AND DISCUSSIONS

4.1. FEA Model and Analysis

To study the change of the mechanical conditions around the crack tip, three dimensional FEM analyses are conducted. Figure 6 shows the kiln models with loadings as required for the analytical and FEA analysis. The full model is analyzed because there is no symmetry line in this problem.

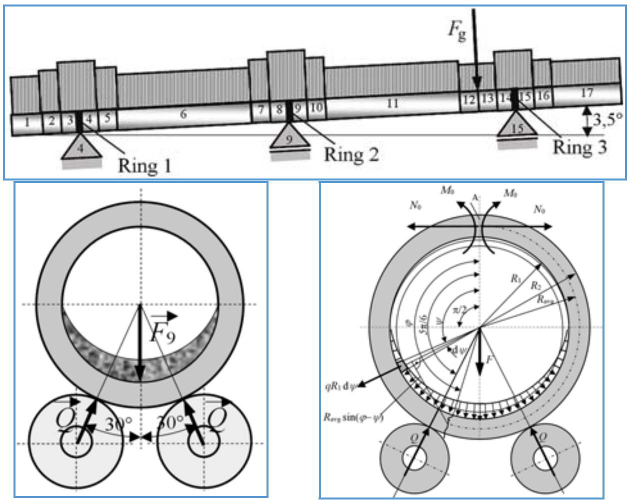


Fig. 6. Support reaction model in kiln ring

Stress distribution in the riding ring can be obtained as a combination of bending, contact and thermal stresses acting in the ring, as a result of distributed load in the kiln, contact between the rollers and the ring, and temperature gradient. In this work, bending stresses are obtained following the work by Maziarz and Tasak **[7]** and Xiao et al. **[8]**, where basic equations are given together with boundary conditions applied in order to obtain bending moments. Contact stresses between kiln rollers and the kiln ring are obtained using classical Hertzian contact analysis **[1].** Thermal stresses are calculated using expressions given by Timoshenko **[2]** and Bowen and Saxer **[9]**.

Figures 7 show the models for the FEM analysis. The full model is analyzed because there is no symmetry line in this problem.

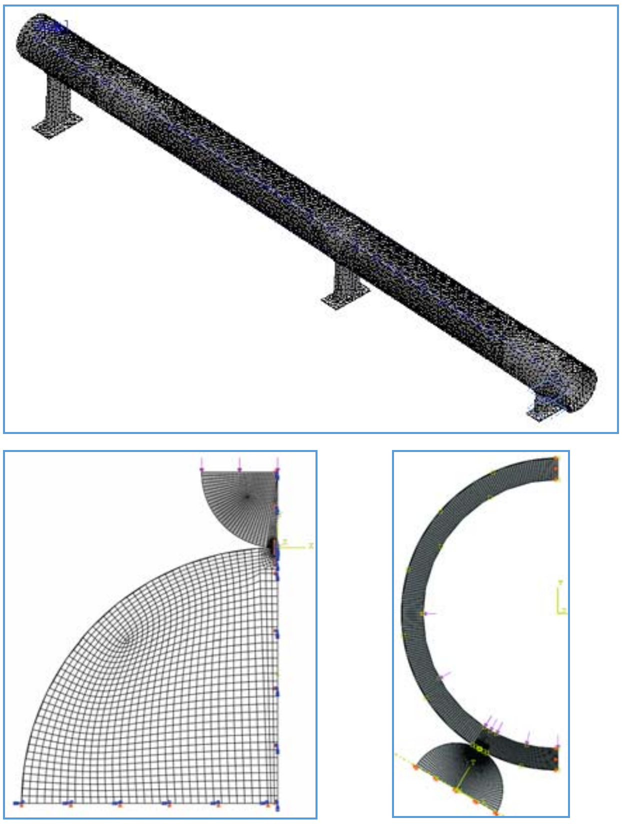


Fig. 7. FEA model of the kiln shell (refined mesh)

Figure 8 is shown the stress around the kiln shell. The results of stress values and the values at the surface and the mid-plane of kiln shell are shown. For every condition, the peak value of the stress range appears on -60º direction, which coincides with the direction predicted by Erdogan and Sih **[10]** criterion. If the stress determines the fatigue crack direction in the mixed mode condition, the crack may grow along this direction.

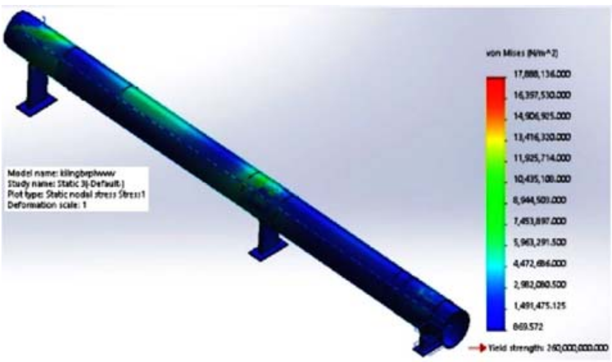


Fig. 8. Stress around the kiln shell

Under static analysis, stress and deformation in the kiln obtained as shown below. From the simulation results are known critical areas that occur in the kiln. Obtained from the static value, subsequent fatigue analysis can be performed. Figure 9 shows the result of a simulation to get the value of S-N curve of the fatigue of the kiln shell from the FEM Software.

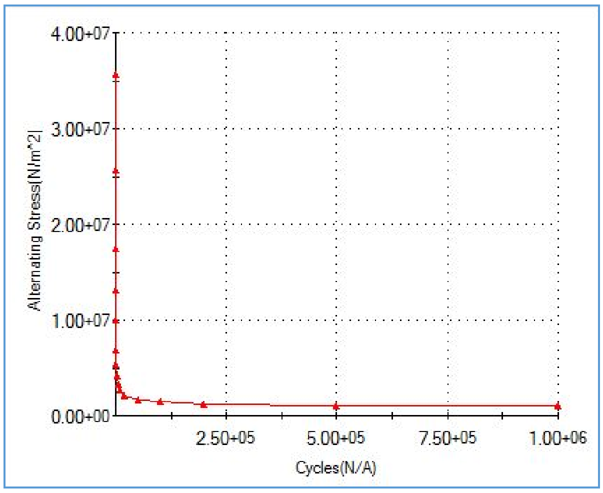


Fig. 9. Total life of the rotary kiln shell (S-N Curve)

And the fatigue life prediction of the kiln shell is shown in Figure 10.

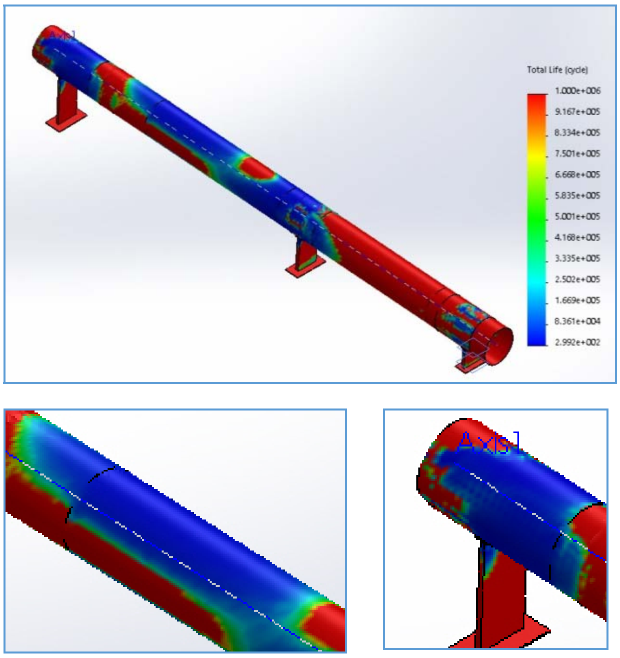


Fig. 10. Fatigue life prediction of the kiln shell

5. RESULTS AND DISCUSSIONS

By FEM modelling, and code assessment, a strategy was developed to assess thermal fatigue of complex mixing problems. In this paper, a description of this strategy along with its application to a specified test case is presented. For the FEA, an experimentally validated FEM model was used. It was demonstrated that temperature data is transferred properly between the two models.

Future work on this subject, based on the availability of experimental data, will be devoted to the application of the described procedure to situations where thermal fatigue has actually appeared or is expected to appear.

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