Application of stiffened plate technique to reduce crack propagation in spring plate of girth gear connector in rotary cement kiln

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Abstract. This paper shows the effect of stiffened plate to the stress concentration and the stress intensity factor of crack on the spring plate. The spring plate has cracked at its base after several years of operation in a kiln in the Semen Padang cement factory. In order to obtain the cause of crack appearing and effect of stiffened plate on spring plate, the finite element model is used to analyze the stress distribution and the stress intensity factor of the crack. In conclusion, the additional stiffened plate is able significantly to reduce the stress concentration and stress intensity factor of crack for both models. The stress concentration can be reduced from 50 to 57 percent with addition of stiffened plate. Meanwhile, the stress intensity factor can be reduced from 63 to 67 percent when spring plate using the addition of stiffened plate. It reveals that the implementation of additional stiffened plate on spring plate has an important role to avoid the crack growth.

1. Introduction
Kiln plays an important role during the cement production process in a cement plant. A rotary cement kiln in general consists of some main components, kiln shell with fire brick inside, kiln tires and tire-bearing to support shell sections, girth gear and pinion for driving system inlet and outlet segment system. The kiln system rotates about three to five rpm constantly with 80 to 100 thousand tons of total weight depending on dimension and capacity of the kiln, and inside temperature excess 1500°C.

Damage occurring in kiln components can cause large losses in the factory, either in terms of loss of time and in terms of material. Therefore, all efforts must be done to make the essential components of this cement plant work well. Many machine elements, particularly the large-sized and heavy weight ones fail not because of being erratically designed or improperly operated but often because of unavoidable defects such as shrinkage pinholes, material porosity, non-metallic inclusions that become an initial crack then by dynamic load its propagates into catastrophic fatigue failure [1]. Some type of fatigue failure that commonly found in rotary kiln components are in tire ring [1], some welded joint component [2], and fretting fatigue fracture of the supporting shaft [3].

Failures in machine components have been caused by a fatigue crack initiated from points having a stress concentration. If the stress concentration level is higher than a critical value, so crack will grow and propagate resulting failure in the machine components. Therefore, it is a useful idea to reduce a stress concentration and then arrest the crack growth by some method before the failure occurring.

A number of researches have been conducted to retard the crack growth of defective machine components such as stop-hole technique by drilling a hole in the crack tip to remove the crack tip singularity [4-6], metal crack stitching, Vee and weld, hammer peening [7], and stiffened plate [8]. Stop whole technique is one of the most practical techniques used to repair method to fatigue crack. These
techniques require a hole of sufficient diameter to be drilled at the crack tip, and it completely reduces the stress concentration on the tip of the crack for successful arrest of the crack propagation.

Girth gear is a gear that is attached to the kiln as one part of the kiln drive system. In general, the kiln drive system consists of a drive motor, pinion and gearch gear as shown in Figure 1. Girth gear is attached to the wall of the kiln using a spring plate. The stiffness of this spring plate should be stiff enough to avoid major deformation of the kiln during operation.

![Kiln, supporting and driving system](image1.png)

**Figure 1.** Kiln, supporting and driving system

This paper will discuss the technique to stop the crack that found in spring plate that supporting the girth gear in a kiln at semen Padang cement factory. The spring plate has cracked at its base after several years of operation like shown in. The shape and position of the crack can be seen in Figure 2. The stiffened bar will be used to reduce the crack propagation by reduce stress concentration and stress intensity factor at the spring plate. Analysis will be done using finite element software.

![Crack in the spring plate](image2.png)

**Figure 2.** Crack in the spring plate
2. Modeling and Load Analysis

Mechanical loads that working in kiln structure is a summation of gravitational load of kiln shell, fire brick, coating material, clinker, girth gear, live ring, and torsional load from the driver [9, 10]. The load distribution of a kiln is described on figure 3. The kiln is rotated three rpm by 1200 kW electric motor power. In general, the consuming power is about 40% of the total power of electric motor.

Therefore, to connect girth gear and kiln shell and to transfer the torsional power, there are 12 leaf springs made from mild steel. The leaf springs transfer the torque from the driver and girth gear weight and gear contact force. The load model of the leaf spring is shown in figure 4. The finite element model of the spring plate is shown in Figure 5. The load in each leaf spring is depending upon the position the spring. The load distribution according to the spring position is shown in table 1. It shows that the spring load is fluctuated along the rotation of the kiln from 66 kN to 105.5 kN in axial $(F_a)$ and 41 kN to 58.2 kN in tangential $(F_t)$ for maximum design, or 14.5 to 54 kN and 11.3 to 28.4 kN for 40% operational load respectively.

![Figure 3. Load distribution of kiln (Rusli, 2017).](image)

![Figure 4. Load model in driving system (left) and load in a leaf spring (right).](image)
Table 1. Estimation of load distribution in different position of the leap spring.

| No spring | Angular position | Full load | 40% load (operational load) |
|-----------|------------------|-----------|-----------------------------|
|           |                  | Axial load (N) | Tangential load (N) | Axial load (N) | Tangential load (N) |
| 1         | 0                | 85,779.8    | 49,680.4                   | 34,311.9       | 19,881.9           |
| 2         | 30               | 90,712.8    | 58,213.8                   | 39,245.0       | 28,415.3           |
| 3         | 60               | 100,569.5   | 58,213.5                   | 49,101.6       | 28,415.0           |
| 4         | 90               | 105,502.1   | 49,679.9                   | 54,034.2       | 19,881.4           |
| 5         | 120              | 100,582.6   | 41,138.7                   | 49,114.7       | 11,340.2           |
| 6         | 150              | 90,726.0    | 41,123.3                   | 39,258.1       | 11,324.8           |
| 7         | 180              | 85,779.8    | 49,649.0                   | 34,311.9       | 19,850.5           |
| 8         | 210              | 80,873.9    | 41,130.3                   | 29,406.0       | 11,331.8           |
| 9         | 240              | 71,017.3    | 41,099.2                   | 19,549.4       | 11,300.7           |
| 10        | 270              | 66,057.5    | 49,617.1                   | 14,589.7       | 19,818.6           |
| 11        | 300              | 70,949.8    | 58,173.9                   | 19,481.9       | 28,375.4           |
| 12        | 330              | 80,806.3    | 58,220.7                   | 29,338.4       | 28,422.2           |

Analysis will be done by calculating the stress intensity factor (SIF) and working stress at the spring plate fillet that generates stress concentration. Crack propagation will be reduce using stiffened plate technique. Two models of stiffened plate will be used in the analysis.

3. Result and Discussion

3.1. Stress Analysis on the spring palate without stiffened plate

In order to obtain the cause of crack appearing as mention early, so the finite element model is used to analyze the stress distribution on spring plate. The spring plate are subjected to loading and supporting system as shown in Figure 5. Figure 6 shows stress concentration at the crack area for 40 percent of operational loading for spring plate without stiffened plate. As seen from figure, the highest stress concentration at area is 235.5 MPa. Furthermore, the highest stress concentration at area increase up to 436.31 MPa for 100 percent of loading (full loading) on spring plate as shown in Figure 7. A large and fluctuating distribution of stress in the fillet area can cause crack growth and propagation on spring plate.
3.2. Stress Analysis on the spring palate with stiffened plate
The one of techniques to avoid the crack occurring is additional stiffener. In this study, two kind of modification with the addition of the stiff plate length are carried out. The first model uses two stiffened plates (Figure 8) and the second model with one wider stiffened plate with a length to the base of 150 mm as shown in Figure 9.
Figure 9. Spring plate model with one stiffened plate

Figure 10 and Figure 11 show the stress concentration at the crack area for 40 percent and 100 percent of loading for spring plate with two stiffened plate (first model). As seen from figure, the stress concentration decrease significantly to 114 MPa for 40 percent of loading as shown in Figure 10. Furthermore, the stress concentration also decreases significantly to 218.4 MPa for 100 percent of loading as shown in Figure 11. The stress concentration reduces about 50 percent for both type of loading.

Figure 10. The stress distribution of spring plate with two stiffened plate for 40 percent of loading
Figure 11. The stress distribution of spring plate with two stiffened plate for 100 percent of loading

Figure 12 and Figure 13 show the stress concentration at the crack area for 40 percent and 100 percent of loading for spring plate with one stiffened plate (the second model). As seen from figure, the stress concentration decreases significantly to 101 MPa for 40 percent of loading as shown in Figure 12. It can be seen that the stress concentration reduces about 57 percent. Furthermore, the stress concentration also decreases significantly to 217 MPa for 100 percent of loading as shown in Figure 13. It can be seen that the stress concentration also reduces about 50 percent.

Figure 12. The stress distribution of spring plate with one stiffened plate for 40 percent of loading
3.3. Analysis of Stress Intensity Factor (SIF) on the spring plate

In order to obtain the effect of stiffener on stress intensity factor of crack, so the crack modelling is used in the finite element analysis the stress on spring plate without stiffener as shown in Figure 14. The crack modelling used is semi-elliptical with 20 mm of major and minor radius. Figure 14 shows that the stress intensity factor is $886.89 \sqrt{\text{MPa mm}}$ for 40 percent of loading. Moreover, Figure 15 shows that stress intensity factor reduce significantly to $326.44 \sqrt{\text{MPa mm}}$ for spring plate with two stiffened plate (the first model). It reveals that the stress intensity factor decrease about 63 percent. Meanwhile, stress intensity factor decrease significantly to $293.95 \sqrt{\text{MPa mm}}$ for spring plate with one stiffened plate (the second model) where the stress intensity factor decrease about 67 percent as shown in Figure 16.
4. Conclusion
In conclusion, the additional stiffened plate has been able significantly to reduce the stress concentration and the stress intensity factor of crack for both model. The stress concentration can be reduced from 50 to 57 percent with addition of stiffened plate. Meanwhile, the stress intensity factor can be decreased from 63 to 67 percent when spring plate using the addition of stiffened plate for 40 percent of loading. It reveals that the additional stiffened plate on spring plate gives effect significantly to avoid the crack growth.

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