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EFFECT OF HOLE DRILLING PROCESSES ON SERVICE LIFE OF BUCKET USED IN BUCKET ELEVATOR

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ABSTRACT

In this study, effect of the hole drilling processes on the service life of the bucket used in a bucket elevator was investigated as a preliminary study to discover the cheapest process while offering suggestions for a longer service life of the buckets. Three processes of drilling are considered; 1) drilling using drilling machine and screw drill (SD), 2) using an NC machine and screw drill (SNC) and 3) using an NC machine and drill first with screw drill, followed by drilling using end mill (ENC). Fatigue tests at two levels of stress amplitude were conducted using an Instron 8801 Servo-Hydraulic Fatigue Testing Machine to apply cyclic load and record the number of cycles to failure. Comparison of the fatigue life among the three processes was reported. Preliminary results show that the ENC process could provide the highest service life. This was about 1.4 times of that of the SD process. Finally, fracture surfaces were observed to explain the effect of the drilling process on service life of the bucket.

KEYWORDS: Crack Initiation, Surface Roughness, Drill Surface Quality, Life Estimation

1. Introduction

The Bucket elevator, as shown in Fig. 1 [1], is a common machine used in almost every production line to elevate the material. At the holes of the bucket which are the position where they were connected with the moving conveyor such as chain and belt [1], damage such as cracks in Fig. 2, bend, tear, and fracture were frequently observed [2-6]. This damage was caused by multiple factors such as surface roughness, high stress concentration, cyclic loading, or combined [7-10], etc. and resulted in not only losses in the downtime of production but also the costs of maintenance, manpower, and the most important, the possibility of injury or fatality. Therefore, understanding the effects which cause the damage and consequently reduction in service life of the bucket is crucial.

In the production line we studied, interview with the operators revealed that when the damage of the buckets were observed, it was very common to continue using them until the buckets broke and fell off the chain. At the time of observation, there were more than 15 broken buckets piling up around the working area, which implies that the damage occurred frequently. According to information from the operators, these buckets were sporadically removed from the working space and sold as scrap. New buckets were produced using SS400 steel sheet because of availability and a reasonable price. However, strength of the materials and details of production, relating to durability of the parts was often ignored. Consequently, replacement parts always have shorter service life compared with original ones. The main challenge in this research is to correlate low-cost production methods and extended bucket service life. As it is known that the drilling process governs average roughness (ranges from 6.3 to 1.6 μm) than milling which gives the range of roughness of 6.3 to 0.8 μm for average applications [11-12]. Therefore, the preliminary study was conducted to find the relationship between hole drilling process and consequent number of cycles to failure of fatigue. Three drilling processes; those are 1) drilling using a drilling machine and screw drill (SD), 2) using an NC machine and screw drill (SNC) to provide elimination of metal scraps and a cooling system and 3) using an NC machine and drilling first with screw drill, followed by drilling using an end mill to smoothen the surface and providing disposal of metal scraps and a cooling system (ENC) were selected. After this, fracture surfaces of failed specimens were investigated. Also, the effect of the drilling process causing hardness around the holes affecting the service life of the bucket was discussed.

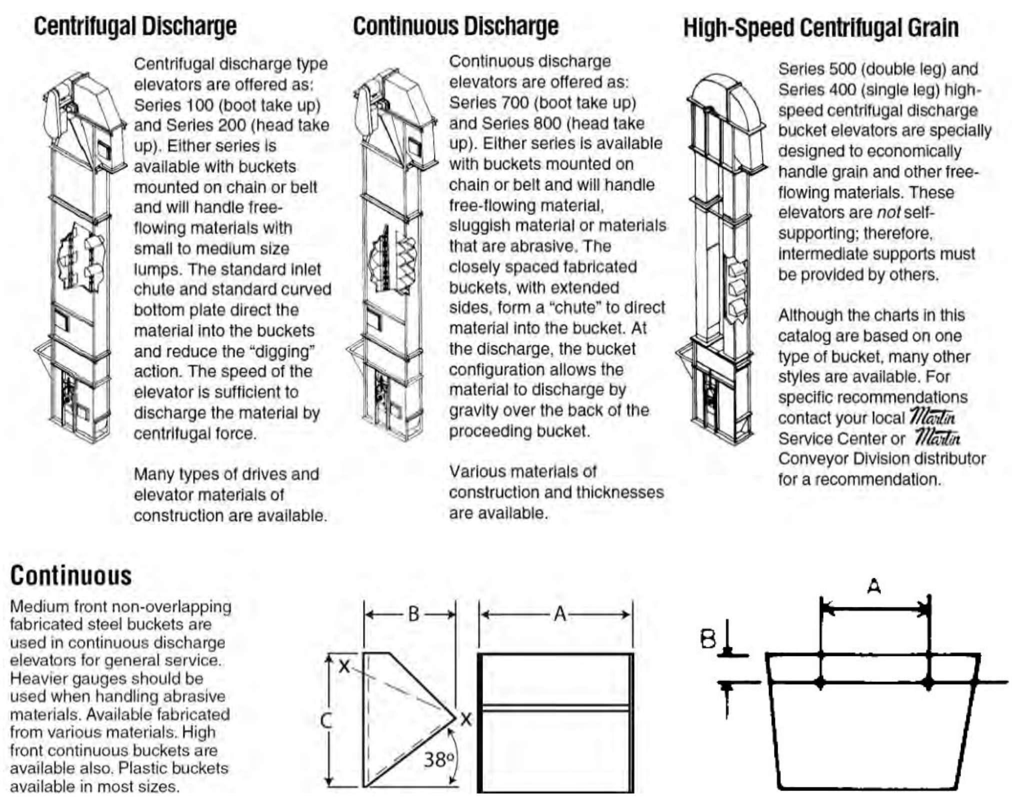

Figure 1 Various types of bucket elevators used in industry [1]

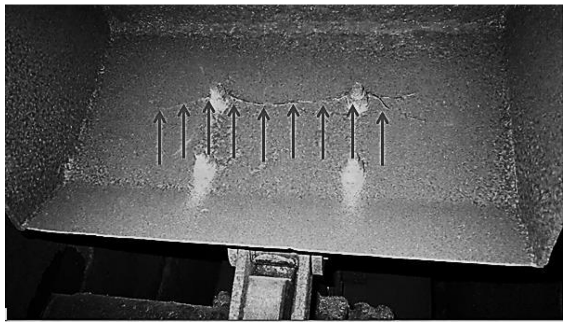

Figure 2 The main crack between two holes with branch cracks present at both edges.

2. Experimental

2.1 Materials and Specimen Preparation

The material used in this study was a 3-mm standard SS400 steel sheet with tensile strength (σ_{UT}) and 0.2% yield strength (σ_Y) not lower than 400 MPa and 245 MPa, respectively. For the cutting direction of fatigue specimens, the longitudinal direction of the test specimens was parallel to the rolling direction of the steel sheet. Shape and size of the specimens was adjusted from ASTM E466-07: Standard Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials [13] due to limitation of the gripping configuration of fatigue testing machine, as shown in Fig. 3. Before test, specimens were ground with abrasive papers number 600 - 1500 grid to remove the existing roughness on the cutting surface. Specimens were then cleaned with acetone in an ultrasonic cleaning machine to remove dirt, oil and metal scraps. Finally, all specimens were kept in a vacuum chamber to prevent dirt, scratches and corrosion.

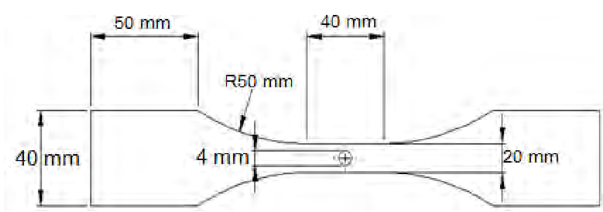

Figure 3 Shape and dimensions of fatigue test specimen with a 4-mm diameter hole

2.2 Hardness test

To measure hardness, a Rockwell tester with a 1.6-mm steel ball was used. A dwell load of 100 kg was applied with dwell time of 30 s. A steel sheet was cut then drilled to obtain a hole with diameter of 4 mm, same size with that of fatigue test piece. Hardness measuring positions were along 4 quadrants of the hole, as shown in Fig. 4. The distances from the center of the hole were chosen at 3, 8 and 13 mm.

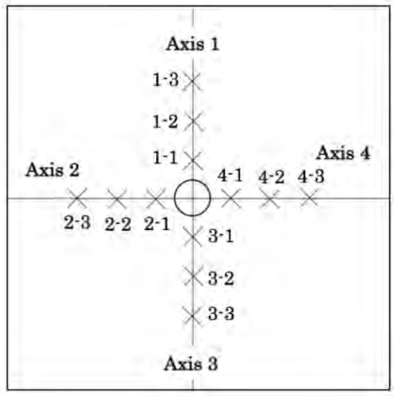

Figure 4 Hardness measuring positions (not to scale)

2.3 Fatigue test

Fatigue tests were conducted according to ASTM E466-07. Instron 8801 servo-hydraulic fatigue testing machine was used in this experiment. Tests were conducted at a stress ratio of 0.1 and a frequency of 15 Hz. Stress amplitude (σ_a) of 123 MPa and 96 MPa were selected to represent the machine operation under high and low cyclic loads. Tests were conducted in a temperature-controlled room of 20°C. The number of cycles to failure at each stress amplitude was recorded. Failure of the specimen was defined as a visible opening or total separation of the specimen into two pieces. To ensure that fatigue initiated from the hole, care was taken during the specimen preparation process.

3. Results and Discussions

3.1 Surface Observation

The color of the original surface of the test specimen is shown in Fig. 5. The quality of the drill surface can be seen in Fig. 6, for the SD, SNC and ENC methods. The degrees of roughness of the hole with different fabrication methods are clearly observed. The roughest surface came from the SD method. These uneven screw marks which were known as the location for high stress concentration were easily visible. The uneven and scratch marks have effect on the service life of the bucket and will be discussed in the topic 3.3. The SNC produced sample has fewer defects and scratches when compared with the SD sample. For the ENC sample, a shiny smooth surface was observed.

Figure 5 Original surface color of fatigue test specimen before grinding.

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Figure 6 Surface quality of a) SD specimen, b) SNC specimen and c) ENC specimen.

3.2 Hardness Test

An average Rockwell hardness value according to measuring positions shown in Fig. 4 was used to predict the effect of work hardening simultaneously with the heat generated from friction. After rearrangement of the data, as shown in Fig. 7, it is clearly seen that the SD specimen has a lower average hardness value when compared with those of the SNC and ENC specimens, with about 6.8% and 7.7%, respectively. For the SNC and ENC specimens, hardness values of both methods show no significant difference, except for the distance of 8 mm from the center of the hole. The hardness value of the SNC specimen shows a lower variance of 2.0% when compared to that of the ENC specimen. Friction developed during the SD process reduces the hardness of steel sheet around the hole. The reason for this reduction is the generation and transfer of heat around the hole. While in the case of the SNC and ENC versions, which were produced using the NC machine, the cooling system helped avoiding the effects of heat. Furthermore, work hardening was generated. Therefore, the hardness value in both cases was higher when compared with the SD process.

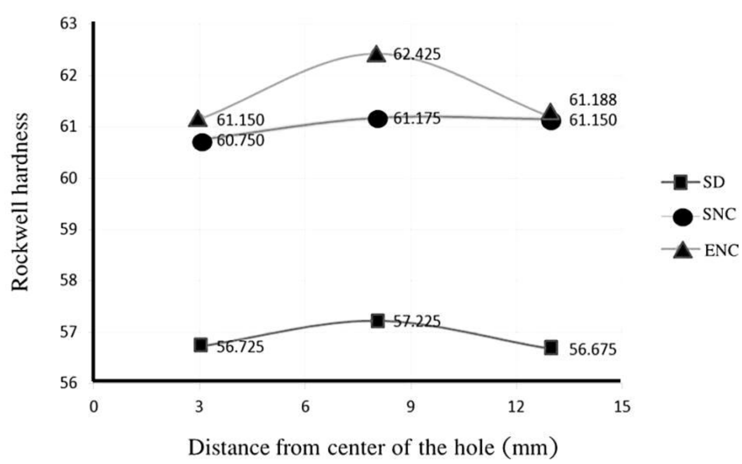

Figure 7 Average Rockwell hardness value at various distances from the center of the hole

3.3 Fatigue Service Life

The results of the fatigue tests of the specimens with hole at two levels of stress amplitude (σa) is shown in the S-N graph in Fig. 8, where x and y axes represent the number of cycles to failure and stress amplitude, respectively. At a stress amplitude of 123 MPa, representing a 'high stress amplitude', the SD, SNC and ENC specimens failed at 108,200, 94,001 and 94,144 cycles, respectively. At this stress level, there was a slight difference in the number of cycles to failure of the SD, SNC and ENC specimens. Although the SD specimen had the longest fatigue life, 1.15 times higher than the SNC and ENC specimens, according to the statistical viewpoint, these data could be considered as a dense group which showed no significant difference. For the SNC and ENC specimens, the fatigue lives of both specimens were almost identical.

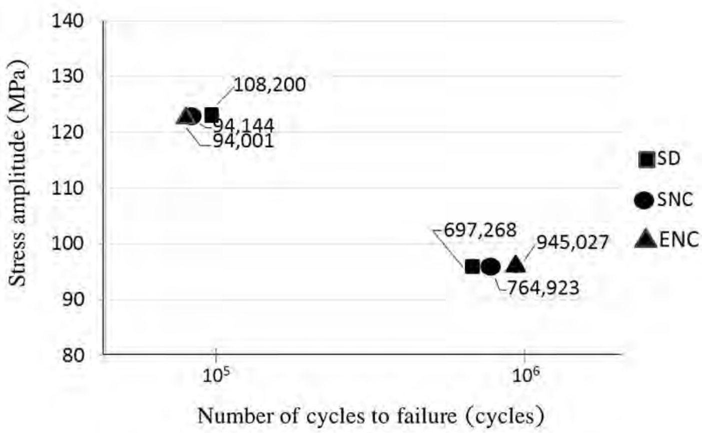

Figure 8 S-N graph of fatigue specimen which has hole at the center of the specimen

In case of fatigue at a stress amplitude of 96 MPa, defined as 'low stress amplitude', results of numbers of cycle to failure showed significant difference. The SD, SNC and ENC specimens failed at 697,268, 764,923 and 945,027 cycles, respectively. Among these three specimens, comparison of fatigue lives showed that the ENC and SNC had higher numbers of cycles to failure by about 1.4 and 1.1 times compared to that of the SD specimen which had lowest number of cycles to failure. Although this study did not illustrate the scattering of fatigue data in the high cycle region, but the scattering effect was studied by other researchers. Mohd, S. et al., studied fatigue strength scatter characteristics of JIS630 stainless steel with duplex S-N curve. In their study, it was found that at 10^6 cycles, which corresponded to the fatigue strengths for the surface-induced crack nucleation mode, scatter of fatigue strength was significantly small. Although surface defects were found in different modes and the materials in the studies was different, but it could be implied that the scatter of the data was small as well. However, to be more accurate, the study of distribution of high cycle fatigue (HCF) tests is strongly suggested. From this preliminary study, the higher number of cycles to failure of the ENC implied to be longest life among three processes.

3.4 Fracture Surface Observation

Fracture surface observation of three types of failed specimens tested at high stress amplitude was compared in Fig. 9. Crack initiation and propagation were in the direction perpendicular to the longitudinal direction of the specimen. At high stress level, numbers of cycles to failure of three types of drilling process were dense in a narrow region. Also, fracture surfaces of the three types of drilling process show similar characteristics; those are clearly visible as ratchet marks. In the case of low stress amplitudes, ratchet marks were visible for the SD specimen, while the SNC and ENC specimens were not, as shown in Fig. 10.

Figure 9 Fracture surface of a) SD, b) SNC and c) ENC fatigue specimen tested at stress amplitude of 123 MPa.

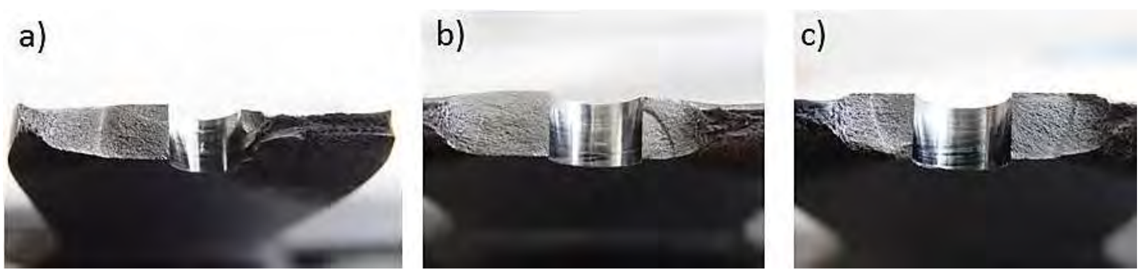

Figure 10 Fracture surface of a) SD, b) SNC and c) ENC fatigue specimen tested at stress amplitude of 96 MPa.

4. Conclusions

From the study of the effect of hole drilling processes on service life of the bucket used in a bucket elevator, it can be concluded that

1) Friction generates heat and work hardening around the hole, which affects the mechanical properties of material.

2) At high stress amplitude, the service life has no significant difference among three types of hole drilling process.

3) At low stress amplitude, the preliminary study implies the ENC provides the highest service life among the hole drilling processes.

4) Since the ENC provides a high possibility to extend the service life of the bucket, scatter of HCF is strongly recommend to be conducted to ensure fatigue result and further the reduction of the costs of maintenance, manpower and the possibility of injury or fatality.

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