Effect of Cold Forging on Wear Resistance of High Carbon Steel for Dolomite Hammer Mill

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Abstract. Hammer mill machine widely use during the process of material reduction in the dolomite industry. The dolomite stone is crushed to the desired shape by the repeated impact of the hammer or crusher. However, since the dolomite stone is milled inside the grinding machine with the help of crusher, it is still challenging because of variety of problem such as the crusher for dolomite hammer mill needs to be changed frequently and no exact data to predict the time taken for the crusher to start wear and how long the crusher can be used before crusher become to wear. In this study, the authors attempt to investigate the effect of cold forging on the wear resistance of high carbon steel for dolomite hammer mill. Specimens of the high carbon steel were prepared for the purpose of this study as per ASTM D695. Cold forging process was conducted using the smith forging method at targeted 3% cold work. Rockwell hardness tester was used to measure the hardness of the specimen. The prototype of the hammer mill machine was used to measure the wear rate to mimic the working principle of the actual hammer mill machine used in the dolomite mining industry. The microstructural analysis was done using a digital metallurgical microscope. The hardness was found to increase from 28.20 HRA to 29.74 HRA for the high carbon steel after conducting the cold forging process. The cold forging process can help to improve the mechanical properties of the material by improving the strength of the material. Moreover, the wear rate of high carbon steel was found to decrease with an increase in hardness. The cold forging process is found to have a significant effect on the hardness and wear rate of high carbon steel. The result obtained in this study is comparable with the previously reported study.

1. Introduction

Crushing is one of the mineral processing operations for rock or ore size reduction into specified shape and size. Nowadays, crushing can be done by using hammer mill machine unlike ancient times, people used two stones or metal to crush the minerals. Hammer mill machine used to process the minerals on small scale and large-scale capacity as the basic principle is to grind large size materials into smaller size [1]. The machine usually consists of crusher, screen, fan that is secure to a circular shape of rotor assembly and located inside grinder chamber. The hammer or crusher inside the machine operated by an electric motor that continuously crush the materials by impact and broke it into smaller pieces. Then the smaller pieces will go through screen which attached underneath to induce particle size and grinding efficiency [2]. Forging is the process of material shaping while increase the strength and toughness of the material, reduce the finished part weight and saving in material [3]. Cold forging is widely used for experiment because it is easy to use and low cost.
There are several studies about cold forging as the yield strength, tensile and hardness increases when the percentage increases due to the energy stored in the material while toughness decreases due to reduction of energy absorbed [4]. The lifespan for crusher in hammer mill machine has shorter lifespan, frequent wear can be seen. Wear can be defined as the mechanical action that removes material from a solid surface [5]. This study is conducted to reduce the hammer mill machine breakdown.

The main objective of this study is to investigate the effect of cold forging on wear resistance of high carbon steel for dolomite hammer mill.

2. Research Methodology

2.1. Materials and Methods

In this study, high carbon steel specimens were prepared for cold forging process. The chemical composition of carbon steel was determined using metal composition analysis and their results are listed in Table 1. The wear test process was summarized in Table 2.

| Specimen | Process | Initial mass average g | Impact time min. | Dolomite sample mass g | Dolomite sample size mm |
|----------|---------|------------------------|-----------------|------------------------|------------------------|
| A, B, C, D | Unforged | 39.25 | 5 | 100 | 5 |
| E, F, G, H |Forging | 39.31 | 5 | 100 | 5 |
| I, J, K, L |Forging | 39.05 | 5 | 100 | 5 |

2.2. Specimen Preparation and Wear Tests

The specimens were cut from the actual hammer mill into 12 rectangular block sizes of 30mm x 12.7mm x 12.7mm by using EDM wire cut. The initial length L₀, initial height H₀, initial width W₀ for each specimen were measured. The initial hardness of each specimen was tested by using Rockwell hardness tester. Eight specimens were selected for the cold forging process. These specimens were forged by smith forging technique by using steel hammer and clamp at room temperature with striking force of 745.79 kN and forging acceleration of 562 m/s². The smith forging was performed up to 1mm length reduction only as targeted cold work of 3%. Further, the final hardness for the specimens was measured to study the changes after cold forging.

After that, hammer mill prototype machine was developed to investigate the wear rate of the specimens. Figure 1 and Figure 2 show the hammer mill prototype model. This machine can fit up to four specimens per batch to crush the dolomite stone samples. Figure 3 shows the rotating shaft with specimen attached. The screen size of 5mm used to filter the dolomite stone before it flows out through the outlet. The initial dolomite grain size on average is 10mm, so when the crushed stone size reduces under 5mm, it will flow out automatically. Figure 4 shows the samples of dolomite stones. The specimens wear rate was measured and calculated by mass loss and studies on the surface conditions by using digital metallurgical microscope.
3. Results and Discussions

3.1. Effect of cold forging on material hardness

Figure 5 shows the representative image of specimen before and after cold forging which shows expansion in the specimen shape due to plastic deformation. Usually, the material must exceed the yield strength in order to achieve permanent deformation through the applied force. The yield strength for high carbon steel is 13.05kN, so as the specimen undergo hammer steel impact that is approximately equal to 745.7903kN, hence it experienced permanent deformation. Once the specimens deformed plastically, the material literally becomes stronger, and this phenomenon is known as strain hardening or work hardening.
FIGURE 6. Hardness of high carbon steel specimens before and after cold forging

TABLE 3. The dimensions, hardness and percentage of cold reduction before and after cold forging

| Process                        | Unforged | Forging |
|--------------------------------|----------|---------|
| Before Cold forging            | Specimens|         |
|                                | A        | B       | C       | D       | E        | F        | G        | H        | I        | J        | K        | L        |
| L₀                             | 32       | 32      | 30      | 32      | 32       | 32       | 32       | 32       | 32       | 32       | 32       | 32       |
| H₀                             | 12.8     | 12.7    | 12.9    | 12.7    | 12.9     | 12.6     | 12.8     | 12.8     | 12.8     | 12.6     | 12.8     | 12.8     |
| W₀                             | 12.8     | 12.7    | 12.9    | 12.6    | 12.8     | 12.6     | 12.8     | 12.8     | 12.8     | 12.6     | 12.8     | 12.8     |
| HRA                            | 30.9     | 31.5    | 25.8    | 26.8    | 30.7     | 30       | 30.1     | 30       | 26.2     | 25.7     | 25.9     | 25.6     |
| After Cold forging             | Lₙ       | -       | -       | -       | 31       | 31       | 31       | 31       | 29       | 31       | 31       | 31       |
|                                | Hₙ       | -       | -       | -       | 16       | 15.7     | 16.2     | 15       | 16.5     | 16       | 15.5     | 15       |
|                                | Wₙ       | -       | -       | -       | 16       | 15.7     | 16       | 15.5     | 16.8     | 16       | 15.3     | 15.3     |
|                                | HRA      | -       | -       | -       | 31       | 31       | 31.5     | 30.2     | 30       | 26.9     | 32.2     | 29.8     |
| Percentage of cold reduction (%)| -        | -       | -       | -       | 3.13     | 3.13     | 3.13     | 3.13     | 3.13     | 3.13     | 3.13     | 3.13     |
On the other hand, final hardness was measured for the 8 specimens after cold forging process as summarized in Table 3. In general, there are some improvements on the hardness when compared to before and after cold forging as shown in Figure 6. The data shows increment of hardness of specimens after cold forging as can recorded in specimens E, F, G, H, I, J, K and L. Noteworthy, the increment of hardness after forging for specimens I, J, K, and L is higher compared to specimens E, F, G and H. It is induced that specimens with low initial hardness benefitted most by cold forging.

3.2. Effect of cold forging on wear resistance

The initial mass, $M_0$ was measured for each specimen before wear test. The data was recorded to study the differences after wear test. Based on Figure 7, specimens A, B, C and D show the average wear amount more than 0.3g. This is due to reaction of wear between the specimen and dolomite stones increases as the duration of wear test increases. Also, the unforged condition of the specimens is one of the reasons for mass loss. Therefore, cold forging specimens shows less mass loss which lead to almost no wear. The specimen J shows the second highest average wear amount which is 0.01083 g since its initial hardness was less which is 25.7 HRA and after the cold forging process increases to 26.97 HRA. This range of hardness is considered low when it is compared with the hardness of other specimens. Through this, it can be inferred that cold forging has significant effect on wear amount of the specimens.

Further, the wear rate of high carbon steel specimens was compared between unforged and cold forged conditions as shown in Figure 8. Specimens A, B, C and D have the highest wear rate compared to other specimens. The mechanical properties of unforged specimens remain the same since it has not undergone any deformation. The main reason is the distance between the dolomite stone and unforged specimens is quite close due to change of dimension compared to forged specimens which undergoes deformation. The unforged specimens can crush the dolomite stones in less time because of high impact between contact surface when distance is smaller, which lead to increase of wear rate. Besides, the surface structure analysis was also studied through digital microscope to examine the wear affect. Table 4 tabulates the uneven surface of unforged specimen A after wear test while for specimen H and J scratch mark can be observed. This is due to the friction between contact surface and dolomite stones. The uneven surface could be also observed in specimen J, however it is not noticeable as specimen A. This suggests that high carbon steel experienced abrasive wear.
FIGURE 8. The wear rate of the high carbon steel for each specimen

TABLE 4. Surface condition before and after wear test for specimen A, H and J.

| Label of specimens | Before wear test | After wear test |
|--------------------|-----------------|----------------|
| A                  | ![Image](image1) | ![Image](image2) |
| (Unforged)         |                 | Uneven surface |
| H                  | ![Image](image3) | ![Image](image4) |
| (Forged)           |                 | Scratch mark   |
| J                  | ![Image](image5) | ![Image](image6) |
| (Forged)           |                 | Uneven surface |
|                    |                 | Scratch mark   |

The wear rate data was articulated against the hardness of each specimen to elucidate the relationship between the wear rate and hardness. Figure 9 shows specimen C has the highest wear rate value which is 1.333 mg/s with the hardness of 25.8 HRA and followed by specimen A with wear rate of 1.161 mg/s and hardness of 30 HRA. The hardness value for both specimens remain same as the initial hardness since it does not undergo cold forging process. The wear rate decreased as the hardness increased due to the increase in strength of hardness of material that undergone cold forging process. The data also indicated that wear rate of cold forged specimens is superior compared to unforged specimens. From this finding, it can be inferred that the cold forging process significantly affects the mechanical properties of high carbon steel through the improvement of hardness through strain hardening mechanism [6,7].
FIGURE 9. The value of wear rate against the value of hardness for high carbon steel

4. Conclusions
The aim of the research is to investigate the wear resistance of high carbon steel and the hardness before and after cold forging process for hammer mill.

- The hardness increased after cold forging process. The cold forging process has effect on the mechanical properties as it is improved in term of material strength.
- The unforged hammer mill can last up to 24 days while for forged hammer mill can last up to 2893.18 days that also equal to 7 years.
- The wear rate decreases after cold forging process. The hammer used in dolomite mining sector can be replaced with forged hammer mill to extend the life span.

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