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EFFECT OF MACHINE DESIGN ON PERFORMANCE OF ORIGINAL EUCALYPTUS BARK CRUSHING MACHINE

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ABSTRACT

In Thailand, eucalyptus is used widely in pulp and paper industry since it grows fast and withstands a harsh and arid environment. Eucalyptus bark, the waste material, is used as a source of renewable energy by crushing it to smaller and shorter lengths. Then, the crushed bark is transferred to the next stage of energy production. As a renewable bio-fuel, eucalyptus bark has a low environmental footprint and low production cost. But the machinery used is a crushing device which is subjected to continuous loading and thus subjected to high levels of failure. In this study, analysis of the design of the crushing machine is conducted together with the determination of predicted failure levels, nature of failure which is wear of the active surfaces, hardness measurements, and microstructural observation using SEM. After that, recommendations for design improvement are proposed.

KEYWORDS: Machine for Renewable Energy, Abrasive Wear, Toughness, Service Life Improvement

1. Introduction

Global warming is partly driven by carbon emissions, proportional to consumption of non-renewable fossil fuels [1-4]. Thus, the use of fast-growing bio-fuels is especially attractive as it is renewable and has a low carbon footprint [5-7]. But processing of the fuel introduces new challenges, transferring the challenges from a thermo-chemical one to a mechanical design one. The vector for this is the cultivation of eucalyptus (a family of dicotyledonous plants placed within the order Myrtales) [8]. Eucalyptus is especially suited to grow in low quality soils and an arid environment. It can be used in the pulp and paper industry. Eucalyptus bark, which is a waste of this industry, is used as a main source for bio-fuel. However, its removal and preparation for use presents new challenges. The schematic picture of production line for bio-fuel production is shown in Fig. 1, those are 1) eucalyptus bark is handled from a storage area to the crushing machine, 2) crushed-bark is transferred to the dryer section (rotating heater) and entered cyclone to separate sizes, and 3) dry crushed- bark is sent to gasifier for energy production. Currently, the process in this study is relatively unreliable, resulting from poor machinery design and leading to poor safety, high levels of maintenance, poor efficiency levels and increased operating costs. For example, the machine fails, typically after 4-6 hours of operation. The crusher blades, comprise 144 pieces, and require replacing, typically after 2 months, primarily related to abrasive damage. Therefore, our study focusses on the design of the crushing machine, excluding human and regulatory parameters, which causing non-uniform crushing operation. Other parameters considered are machinery assembly and arrangement of the crushing blades, determination of predicted failure levels, nature of failure which is wear of the active surfaces, hardness measurements and microstructural observation using a SEM. Finally, recommendations for design improvement are proposed.

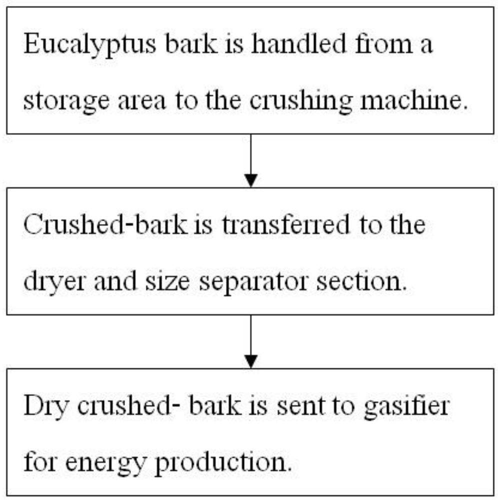

Figure 1 Schematic picture of production line for bio-fuel production

2. Inspection of the Original Machine

2.1 Design of the Eucalyptus Bark Crushing Machine

Assembly of eucalyptus bark crushing machine in this study is shown in Fig. 2. Main components are 1) a 270 HP/ motor at 1,480 rev/min, 2) a 45 mm-diameter main shaft, 3) a set of 144 pieces crushing blades, 4) two screens rated at 1.5-inch diameter, 5) a screen locking set, 6) a machine base with door-sliding guides and 7) a housing and two sliding doors. Material of construction is SS400 steel. The material of the crushing blade is 5mm-thick SS400 steel sheet with crushing blades welded along the perimeter. Welding is designed to maximize surface hardness. However, according to the person in charge of the machine, information of welding method and parameter could not be traced back.

2.2 Conveying System of Material into and out of the Machine

Coarse bark is pushed by a screw conveyor to the entry section at the top of the crushing machine housing, as shown in Fig.3. Since the longitudinal directions of the screw conveyor and the main shaft are parallel, most of the coarse bark drops first and unevenly, loading the machine more on one side than the other. After passing the crushing process, the bark meeting the desired size passes through the filter screens, flowing downwards to the belt conveyor located below the housing. Non-specification bark will still be trapped inside the machine and the crushing process repeated until the bark meets specification.

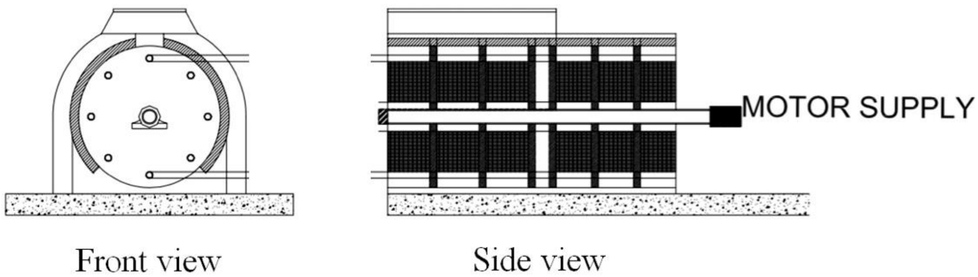

Figure 2 Eucalyptus bark crushing machine assembly

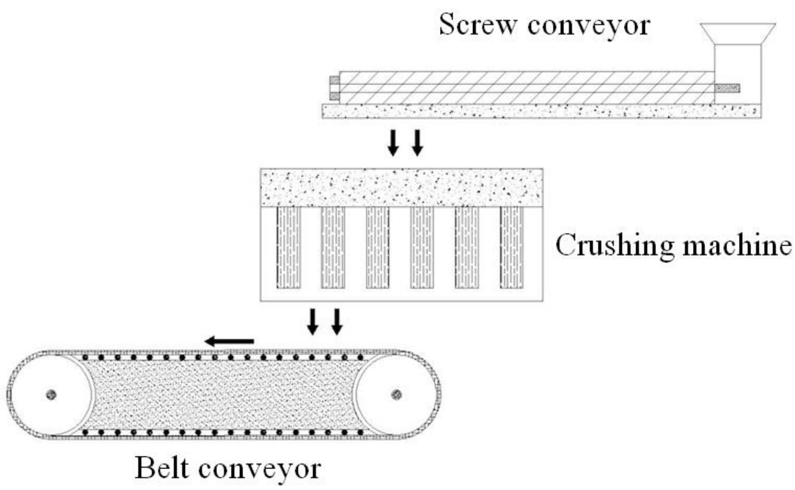

Figure 3 Material transfer system of the crushing machine

2.3 Arrangement of crushing blades

Figure 4 shows the arrangement of the crushing blades comprising 144 crushing blades (8 supports×18 pieces/support arranged in 6 sections x 3 pieces/section). The gap between each crushing blade in each section is 60 mm. The minimum gap between blades in section 1&2, 2&3, 4&5 and 5&6 is 90mm. The maximum gap is found at mid-length of the shaft (between sections 3&4) with a length of 200 mm.

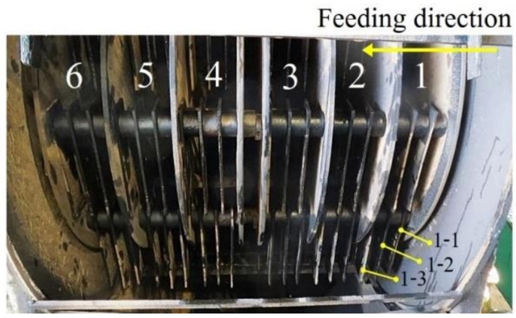

Figure 4 Arrangement of the crushing blades

3. Results of Analysis of Machine Design, Conveying System, and Arrangement of Crushing Blades

3.1 Effect of Machine Design

According to the design of the crushing machine, spacing between the filter screen and the cover is 50 mm. This is too narrow and allows the mix of moist, dry and sticky bark to clog at the arm of the screen-locking set, so the leftover bark between filter screen and the cover blocks. Additionally, the door-sliding guides obstruct the flow of crushed bark to the lower conveyor belt. This is shown in Fig. 5. Since the crushed bark is compacted and cannot move away, it compacts further to the inside of the crushing chamber, obstructing the motor and causing the motor to overload and trip and the machine to stop.

Figure 5 Jamming of crushed bark between the screen and the cover

Visual inspection of the used crushing blades is shown in Fig.6. The damage is roughly categorized into 4 types, those are a) slight corner damage, b) knife-like shape damage, c) square-cut damage, and d) mixed of type b) and c). These wear feature suggests that the material used is improper because it cannot resist abrasive wear and that the welding along the perimeter of the crushing blades does not improve wear resistance as expected. Vickers hardness of the failed knife-like shape crushing blade in Fig. 6b) is studied. The Hardness value at various positions on the cross-section of the wear piece was measured according to ASTM E384-11 [9]. The result is shown in Fig. 7. The bulk material (position 4, 5 and 6) has Vickers hardness value of about 150. In the welded areas (position 1, 2 and 3), the Vickers hardness value varies according to the position of measurement from a minimum of 325 to a maximum of 425. An average value of 375 is significantly higher compared to the bulk material (by 2.5 times). At severe wear positions 7 and 8, there are no significant changes in hardness value from the bulk material. However, position 9 which is the edge of the crushing blade experiences both abrasive wear and direct impact with the bark, therefore resulting in thinning of the material and bending of the edge, respectively. Hardness value at this point then has a slightly higher value of 375 due to abrasive wear and plastic deformation of bending part, as seen in Fig. 8 for visual and microstructural observations.

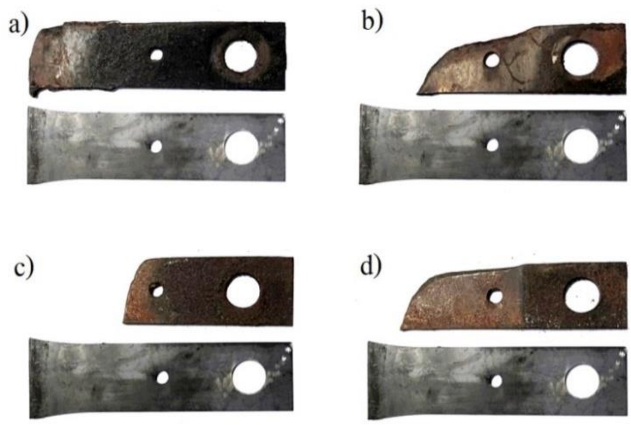

Figure 6 Various shapes of failed crushing blades compared to the original shape

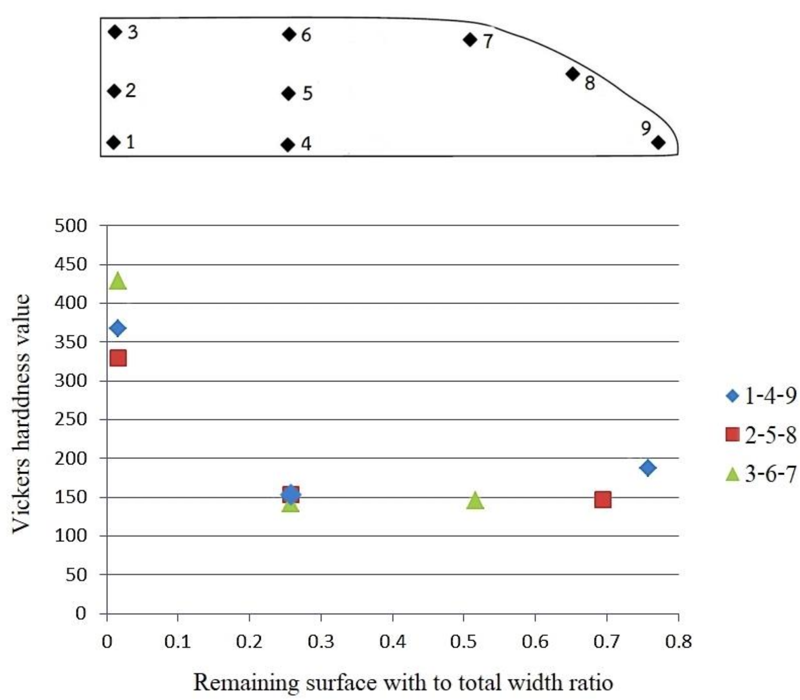

Figure 7 Vickers hardness measuring positions and corresponding value

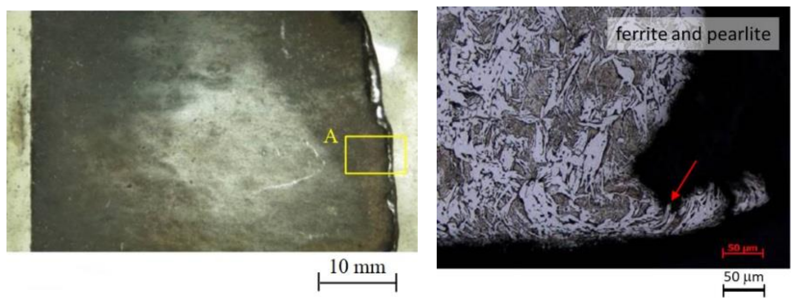

Figure 8 Plastic deformation on the crushing blade

For microstructural observation of the failed knife-like shape crushing blade, 3% Nital is used as an etchant [10]. Etching results show the bulk material has ferrite and pearlite structures, as seen in Fig. 9. The cutting edge of crushing blade has fine bainite structure, while the phase transformation from the bulk material might result from the heat effect during cutting and welding along the perimeter of the blade. At the most severe abrasive wear zone, no transformation of microstructure observed. This implies no heat effect is involved during the wear process. On the opposite surface as well, there is no phase transformation, but plastic deformation is observed. Because of thinning of the edge of crushing blade, local stress reaches the yield strength of the material and therefore plastic deformation of the edge of the crushing blade occurs.

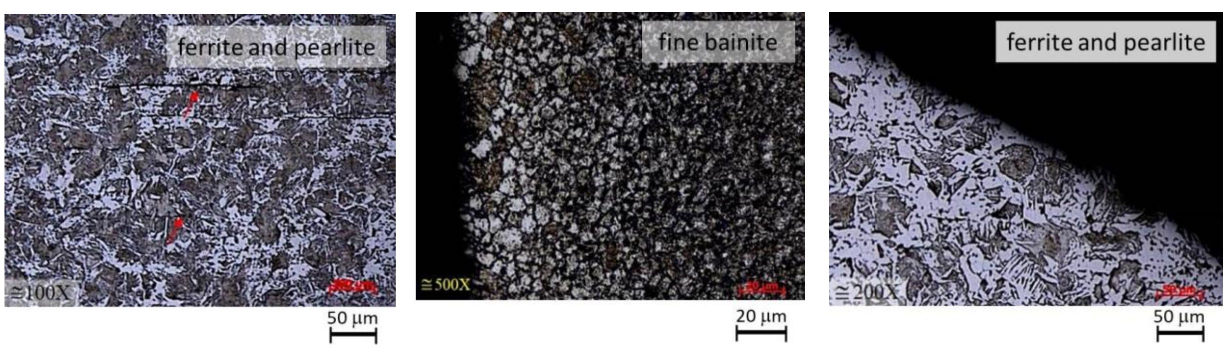

Figure 9 Microstructure of the crushing blade a) bulk material, b) edge area and c) severe wear zone

3.2 Effect of Conveying System

According to Fig. 3, since the longitudinal direction of the screw conveyor and the main shaft is parallel, most of the coarse bark drops on one side of the machine (section 1 and 2). Visual inspection shows a difference degree of wear, as seen in Fig. 6. The abrasive direction is related to the direction of rotation of the main shaft (Fig. 10). On the section with larger material drops on, severe abrasive wear is clearly seen. On the other side with lower material drops, slight delamination of the weld and minor wear is observed, as seen in Fig. 11. Although blades in section 3 to 6 crush the eucalyptus bark less than those in section 1 and 2, wear or the blades still be observed. A possible factor accelerating the abrasive wear of the crushing blades is congestion of crushed bark inside the crushing chamber. Another possibility is that small crushed particles become stuck between the supports and crushing blades, therefore the blades cannot rotate freely causing abrasive wear.

Figure 10 Corresponding abrasive directions with shaft rotating direction.

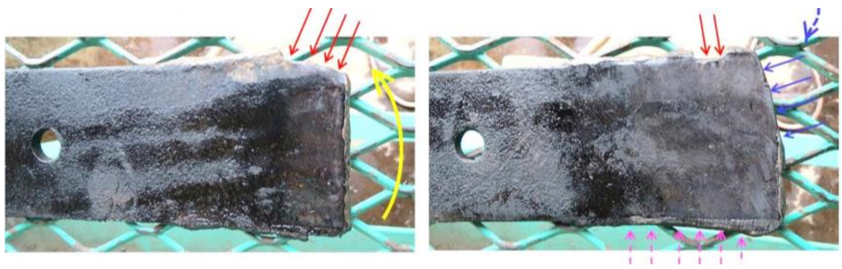

Figure 11 Delamination of the weld follows by minor wear

3.3 Effect of the Arrangement of the Crushing Blades

As shown earlier in Fig. 4 that each support of the blades is divided into 6 sections, with 3 blades/section. Section 1 has the most severe wear (Fig. 10), while section 6 has minimum (Fig. 11). Within each section, three blades have different degrees of wear as seen in Fig. 12. Blade No. 1-1 has a higher level of wear with a knife-like shape, while blade No.1-3 has lower wear rate and consequently has a blunt shape with one cut corner. The difference of shape of these two blades is believed to be primarily due to the feeding system feeding material to blade No.1-1 more than blade No. 1-3. In case of blade No. 1-2, located between blade No. 1-1 and 1-3, with minimum spacing (60mm) made blade No. 1-1 and 1-3 as shields that protect blade No. 1-2 from direct contact with the bark. Therefore, a very small amount of weld delamination and wear was observed. In section 6, at the furthest end of travel of screw conveyor, very light wear was observed. This was due to the feeding system spreading the material to the first and second section in preference to the others. Once severe wear occurs, all 144 blades have to be changed, wasting spare parts, time and energy production.

Figure 12 different level of wear in a section

High-magnification observation of various wear area by SEM is shown in Fig 13. Area A and B are the edge of the specimen where maximum abrasive wear occurs and the face width on this side is thinner than the opposite side. In these areas, coarse pitting is easily seen. However, in area C where wear is observed, but the removal of material is in the parallel direction. Observed macroscopically, thickness of the crushing blade at this cross section is constant.

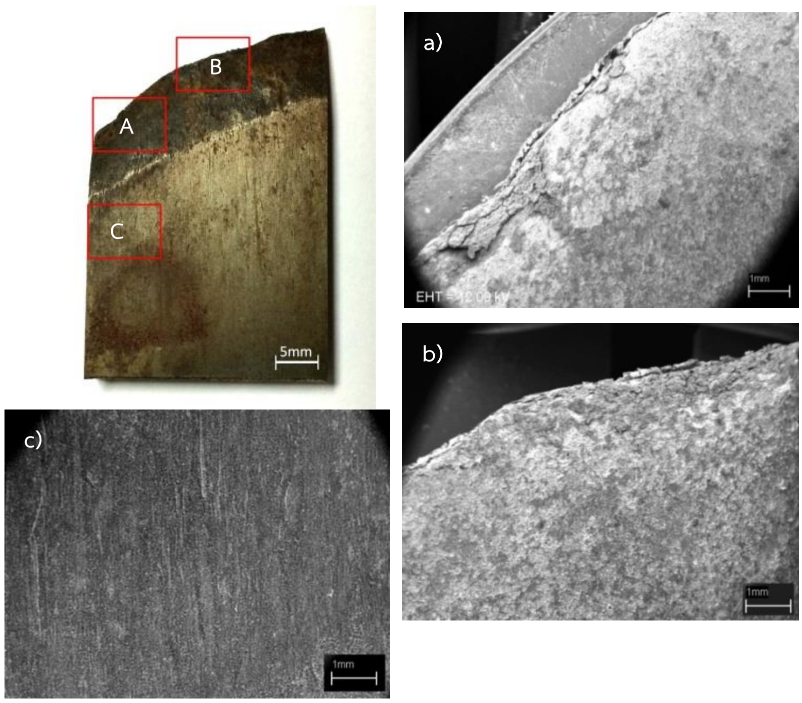

Figure 13 SEM observation of various wear areas

Conclusions

From the study of effect of machinery design, material flow and blade arrangement of a eucalyptus bark crushing machine, it can be concluded that

1) The feeding system of coarse bark should be modified to distribute the material to the crushing chamber evenly. In this case, all 144 blades will experience an even wear rate. Furthermore, it is suggested to oscillate the direction of rotation, so that both sides of the crushing blades have a similar wear rate. By doing this, the service life of the crushing machine will be enhanced.

2) Changing or modification to the spacing between the cover and the screen is difficult. Thus a force-draft system is suggested to prevent jamming and smoothing the flow of crushed bark to the lower conveyor belt.

3) Welding along the perimeter of the crushing can increase the hardness of the surface. However, the hard layer is very thin and brittle causing delamination which does not prolong the service life of the crushing blades.

4) Since changing or modification of the arrangement of the crushing blade is difficult, changing its material to a higher hardness and toughness will be beneficial.

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