Study of welding deposition performance in changing parameters (welding speed and direction) in hard coating application in sugarcane mills using the FCAW process with a focus on sustainable manufacturing

Estudo do desempenho de deposição de soldagem em mudança de parâmetros (velocidade e direção de soldagem) em aplicação de revestimento rígido em usinas de cana-de-açúcar usando o processo FCAW com foco na fabricação sustentável

DOI: 10.54033/cadpedv21n1-113
Recebimento dos originais: 12/12/2023
Aceitação para publicação: 15/01/2024

Márcio de Queiroz Murad
PhD in Mechanical Engineering from the Universidade Federal de Uberlândia
Institution: Universidade Federal do Triângulo Mineiro (UFTM)
Address: Av. G. Guaritá, 159, Nossa Senhora da Abadia, Uberaba - MG,
CEP: 38025-440
E-mail: marcio.murad@uftm.edu.br

Valtair Antonio Ferraresi
PhD in Mechanical Engineering from the Universidade de Campinas
Institution: Universidade Federal de Uberlândia (UFU)
Address: Av. João Naves de Ávila, 2121, Santa Mônica, Uberlândia - MG,
CEP: 38408-100
E-mail: valtair@ufu.br

ABSTRACT
Being one of the main sources of waste generation from welding processes, filler metal splashes are a source of waste generation that promotes environmental impacts due to their chemical compositions. Actions that converge towards reducing waste, in addition to mitigating environmental impacts, also represent a significant contribution to reducing costs inherent to welding processes. Actions aimed at reducing waste and costs contribute significantly to sustainable production. In this context, a study is proposed that analyzes welding spatter as a contaminating residue and loss of financial resources. Therefore, the objective of this study is to analyze the application of hard coating using the FCAW (Flux-Cored Arc Welding) process on shafts in sugar and alcohol plants. The objective is to study the influence of the coating application speed parameter associated with the direction of rotation (welding direction) on the Deposition Yield. As proposed in this study, using welding speeds of 6, 10 and 13.6 m/min with alternating rotation directions (clockwise and counterclockwise), the Deposition Yield was
calculated for the 6 situations. The results showed an improvement in performance when 6 m/min and clockwise were combined. This improvement results in savings of approximately R$6.7 million per year and would avoid the generation of 385 tons of hazardous materials in Brazil. These results contribute to more sustainable production.

**Keywords:** sustainability, sustainable manufacturing, welding, deposition yield, mills.

**RESUMO**
Sendo uma das principais fontes de geração de resíduos a partir de processos de soldagem, as chapas de metal de enchimento são uma fonte de geração de resíduos que promove impactos ambientais devido à sua composição química. As ações convergentes para a redução dos resíduos, além de mitigar os impactos ambientais, também representam uma contribuição significativa para a redução dos custos inerentes aos processos de soldagem. As ações destinadas a reduzir os resíduos e os custos contribuem significativamente para uma produção sustentável. Nesse contexto, propõe-se um estudo que analisa respingos de solda como um resíduo contaminante e perda de recursos financeiros. Portanto, o objetivo deste estudo é analisar a aplicação de revestimento rígido utilizando o processo FCAW (Flux-Cored Are Welding) em eixos em usinas de açúcar e álcool. O objetivo é estudar a influência do parâmetro de velocidade de aplicação de revestimento associado ao sentido de rotação (direção de soldagem) no rendimento de deposição. Como proposto neste estudo, utilizando velocidades de soldagem de 6, 10 e 13,6 m/min com direções de rotação alternadas (sentido horário e anti-horário), o Rendimento de Deposição foi calculado para as 6 situações. Os resultados mostraram uma melhora no desempenho quando 6 m/min e no sentido horário foram combinados. Essa melhora resultaria em uma economia de aproximadamente R$ 6,7 milhões por ano e evitaria a geração de 385 toneladas de materiais perigosos no Brasil. Estes resultados contribuem para uma produção mais sustentável.

**Palavras-chave:** sustentabilidade, fabricação sustentável, soldagem, produção de deposição, moinhos.

**1 INTRODUCTION**
Welding processes are widely used in various areas of the sugar and alcohol industries, both in maintenance actions and also in the application of coatings to increase the useful life of equipment [1].

To protect sugar cane mills, the FCAW process is used as a metallic coating to protect the mill rolls from wear. No different from other welding processes, FCAW generates metallic waste that causes negative environmental impacts [2],

**REVISTA CADERNO PEDAGÓGICO** – Studies Publicações e Editora Ltda., Curitiba, v.21, n.1, p. 2199-2217. 2024
and such waste may increase in generation due to the inefficient use of energy and materials [1].

The sugar and alcohol sector considers mitigation of environmental impacts and more sustainable production to be one of its goals. This industrial segment has a culture of innovation with great potential for action in renewable energy, biofuels, bioelectricity and biomaterials [3].

For Sharma [2] and Wang [4] the adoption of actions that aim to reduce waste generation with the efficient application of welding techniques, when adopted and practiced, contribute to more sustainable processes [5]. One can exemplify how these actions are the corrective and preventive maintenance practices that are adopted by the sugar and alcohol sector, which aims to increase the reliability levels [6] of mills, equipment intended for the sugarcane juice extraction process. sugar, exposed to aggressive media, and subject to severe wear [7,8], as shown in Figure 1.

Figure 1 – Milling shafts after operation

Source: Murad et al., 2020.

As this is a continuous process sector, the levels of operability and reliability affect extraction yields, so layers of hard coating are added to the mill grooves [1]. This coating is called roughcast and can be applied using the Shielded Metal Arc Welding (SMAW) or Flux-Cored Arc Welding (FCAW) welding processes [1, 9]. The construction of the protective coating for the mill teeth consists of the perforated elements, base on base, sides and roughcast, as shown in Figure 2. [1,9]. It is common to apply coatings with alloys composed of
chromium, such components form chromium carbides [10]. It is common to use Fe-Cr-C alloys [7].

According to Sharma et al. [1] reductions in waste emissions and costs are aspects related to sustainability and are directly correlated to welding parameters, and these directly affect Deposition Yield (Rd), such as welding speed. In the same line of thought, Lima and Ferraresi [10] demonstrated in their study that the welding direction also has an effect on the change in deposition yield. Other authors such as Nath et al. [11] also investigated the influence of the welding direction and the angle of the electrode in relation to the base material on the quality obtained and its deposition yields. In the same line of thought, Sproesser et al. [15] and Chucheep et al. [16] when studying the correlations between Welding Voltage (U), in different welding processes, they considered welding speed as a decisive factor to obtain better Rd. It is evident that changing welding parameters has a strong influence on Rd and that such parameterizations would result in different quality indexes.

Specific studies for mill shafts, such as Santos [13], showed yields of 50% for FCAW and 30% for SMAW, but did not present the parameterizations used. This demonstrates possibilities for studies for the agribusiness segment and for currency axes.

Traditionally, Rd is obtained by Equation (1)

\[
Rd = \frac{(W_f - W_i)}{W_{aran} \cdot L_{aran}}
\]  

(1)
Where:

\[ W_f \text{ is the final weight, } W_i \text{ is the initial weight, } W_{\text{arame}} \text{ is the weight of the wire and } L_{\text{electode}} \text{ is the length of the electrode.} \]

In the case of mill shafts, due to the difficulty of weighing the mill (estimated weight of 50 tons), \( R_d \) can be obtained by the ratio between the weight of the wire applied during a given time and the material that was not adhered (splash) during the welding process \([1, 9, 17]\).

Regarding the welding speed, for this study, it will be defined as Sheet Application Speed (Vc) since the focus of this study is the application of hard coating on milling shafts and the welding current as Sheet Metal Current (Ac).

Considering that any filler metal that is not added to the mill shaft will become waste and this will become environmental contamination and consequently economic losses for the company. For Standard ABNT NBR 10.004 \([14]\) which suggests the classification of hazardous solid waste, which are those that present dangerousness associated with the characteristics of flammability, corrosivity, reactivity and pathogenicity. In this context, the waste generated by the welding process for lining sugar cane mills is considered hazardous solid waste.

Considering the social and economic impacts of the company, it tends to add more value to its goods and services, in addition to strengthening its image in the market \([17, 18]\). Sproesser \textit{et al.} \([15]\) and Chucheep \textit{et al.} \([16]\) considered welding sustainable in relation to economic and environmental dimensions and carried out studies comparing different welding processes, pointing out the differences regarding the sustainability of these processes.

In light of these purposes, the objective of this article was to carry out a study where the values of Vc and U were changed and analyzed their implications on \( R_d \), and consequently the impacts generated in the reduction of waste and costs, in the application of hard coating in sugarcane mills of sugar (during the mill’s preparation phase for the harvest). With these changes, we analyze the sustainability aspects of this manufacturing process in the sugar and alcohol sector, specifically the generation of waste from the application of metallic coating.
through the tubular wire welding (FCAW) process and the economic aspects related to the process. Therefore, studies were conducted along two distinct lines: a) Economic and Technological, focusing on improving the application by changing welding parameters; b) Environmental: focusing on waste generation and energy efficiency.

2 METHODOLOGY

The tests were carried out in a company located in the interior of the state of São Paulo, which is currently a reference in the sugar and alcohol market in the sale of cast and machined products. The company allowed access to its plant and, specifically, to the welding department where the tests for this study were carried out, in addition to providing the necessary inputs for this experiment as well as technical support.

A welding system consisting of a double torch (Figure 3) is used to apply the hard coating to the milling liners. Composed of a set with a feeder carriage installed on a ruler that provides horizontal movement. The milling jacket is mounted in a horizontal position on a mechanical device that gives it a rotation that, in turn, can be varied using a frequency inverter and also allows the clockwise and counterclockwise direction to be inverted (Figure 3). Depending on the operational procedures adopted by the company, Vc can be varied between 2 and 20 m/min, with the most used being 10 m/min. The liner must be supported on rollers or bearings so that there is no slippage during work, ensuring perfect alignment with the hard coating application device.

![Figure 3 – Direction of Rotation](source: Authors)
The application of hard coating is done by a set of welding equipment, consisting of:

a) Welding source with capacity of 600 A at 100%.
b) Feeder head for 2.8 mm tubular wires.
c) Processing Unit – PLC, which activates and controls the motors of the advancement and positioning axes. Such movements are controlled by position sensors mounted on the equipment. A Human – Machine Interface (HMI) unit allows the necessary programming variation adjustments that can be made by the operator.

The base metal used was nodular cast iron Type GGG-60, in accordance with DIN 1693.

The filler metal was a self-protected tubular wire, with a hardness of 57 to 62 HRc, a diameter of 2.8 mm. Table 1 presents the chemical composition of the filler metal provided by the manufacturer. It is a product specially designed for applying hard coating to mill liners.

<table>
<thead>
<tr>
<th>C</th>
<th>Cr</th>
<th>Si</th>
<th>V</th>
<th>Mn</th>
<th>Fe</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.64%</td>
<td>16.81%</td>
<td>1.05%</td>
<td>0.50%</td>
<td>0.82%</td>
<td>76.61%</td>
<td>0.01%</td>
<td>0.02%</td>
</tr>
</tbody>
</table>

Source: Murad et al., 2020.

The most common process for obtaining Rd, the ratio between the molten metal and that actually deposited, is carried out by weighing the metal before and after applying the coating. Due to the difficulty of weighing the mill (estimated...
weight of 50 tons), Rd was obtained in this work by the relationship between the weight of the applied wire and the spattered material (metal that was not adhered to the mill). The value obtained does not represent reality in terms of Rd (flux fusion of the tubular wire), but it is possible to obtain a value that can be compared with others using the same technique. To obtain the weight of the splashed material, the following procedures were used: i) A metal collection container with approximately 60 liters in volume was used, equipped with a hole for water drainage; ii) The collection container was inserted below the torches and the base metal (mill liner), for a period of time of one minute (field test time). Performed three times for each sample; iii) Using a metal sieve, the solid material was first separated from the liquid; iv) The material was dried in an oven and subsequently weighed on an analytical balance with a capacity of 4200 g and a reading of 0.01 g.

To obtain the weight of the applied material (filler metal), the following procedure was used: i) The amount of wire that the source provides during the application of the hard coating was collected (for one minute); ii) Subsequently, it was weighed on an analytical balance with a capacity of 4200 g and a reading of 0.01 g; iii) As the process uses two torches to apply the hard coating under the same application conditions, the value obtained was divided by 2, to obtain the values of the spattered material; iv) This procedure was repeated for the 3 collections.

Based on the conditions used by the company, in which it adopts speed $V_c = 10$ m/min, $V_c$ was varied (6 and 13.6 m/min) with the aim of understanding and finding new parameters with better application conditions, that is, better Rd, and these values are presented in Table 2.

<table>
<thead>
<tr>
<th>$V_c$ (m/min)</th>
<th>$U_d$ (V)</th>
<th>$V_a$ (m/min)</th>
<th>Application</th>
<th>$D_{PP}$ (in)</th>
<th>$A_c$ (deg)</th>
<th>Clockwise</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>31</td>
<td>3.2</td>
<td>Water</td>
<td>24</td>
<td>35</td>
<td>H</td>
</tr>
<tr>
<td>10</td>
<td>31</td>
<td>3.2</td>
<td>Water</td>
<td>24</td>
<td>35</td>
<td>H</td>
</tr>
<tr>
<td>13.6</td>
<td>31</td>
<td>3.2</td>
<td>Water</td>
<td>24</td>
<td>35</td>
<td>H</td>
</tr>
<tr>
<td>6</td>
<td>31</td>
<td>3.2</td>
<td>Water</td>
<td>24</td>
<td>35</td>
<td>AH</td>
</tr>
<tr>
<td>10</td>
<td>31</td>
<td>3.2</td>
<td>Water</td>
<td>24</td>
<td>35</td>
<td>AH</td>
</tr>
<tr>
<td>13.6</td>
<td>31</td>
<td>3.2</td>
<td>Water</td>
<td>24</td>
<td>35</td>
<td>AH</td>
</tr>
</tbody>
</table>

Legend: $U_d$ desired voltage (V), Dry or wet application, $D_{PP}$ = Nozzle Contact Part Distance (mm), $V_a$ = electrode wire feed speed (m/min) $A_c$ = Application Angle (degrees) and clockwise (H) or counterclockwise (AH)

Source: Murad et al., 2020.
In order to obtain the current and voltage values from the tests carried out during the field experiment phase, equipment with a recording capacity of 10 kHz was installed for subsequent analysis. The equipment used was a Lynx ADS1800.

4 RESULTS AND DISCUSSIONS

With the hard coating application conditions employed by the company and with variation in Vc, values relating to the weight of the deposited material were also obtained, such as the mass of the Electrode Wire (Al) and the Splash (Resp). Spatter refers to the material that did not adhere to the mill frize, collected during the test to determine Rd.

The first tests carried out in the field were with the company's hard coating application parameters, and are presented in Table 3. The other tests with Vc of 6 and 13.6 m/min, presented in the same table, were proposed by research with the objective of understanding the effect of this variable on the appearance of the hard coating and mainly on Rd. In addition to the variation in Vc, the direction of rotation was changed.

For each application condition, Im and Um measurements corresponding to the average of the samples obtained in the tests through the data acquisition system were obtained. The application conditions remained constant, as already shown in Table 3. The test time was 1 minute, water was applied to the electric arc.

It can be seen in Table 3 that there is a difference between the desired values Ud and the average voltage values (Um) obtained by the acquisition system. As it is equipment built specifically for the application of hard coatings, it is not possible to change the values on the equipment, as it would be different from those carried out by the company.

A statistical analysis of Rd was carried out as a function of Vc and direction of rotation, defining a significance level of 5%, that is, a reliability of 95%. All are characterized as statistically different, with a reliability of 95%.
### Table 3 – Results obtained with variation of Vc

<table>
<thead>
<tr>
<th>Clockwise</th>
<th>Ud</th>
<th>Va</th>
<th>Um</th>
<th>Im</th>
<th>Vc</th>
<th>Al</th>
<th>Resp</th>
<th>Rd</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(V)</td>
<td>(m/min)</td>
<td>(V)</td>
<td>(A)</td>
<td>(m/min)</td>
<td>(g)</td>
<td>(g)</td>
<td>(%)</td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>6</td>
<td>188,0</td>
<td>61,69</td>
<td>67,19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>36.4</td>
<td>313,1</td>
<td>6</td>
<td>188,0</td>
<td>64,50</td>
<td>65,69</td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>6</td>
<td>188,0</td>
<td>66,73</td>
<td>64,51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Rd</td>
<td>65,69</td>
<td>Standard Deviation of Rd</td>
<td>1,34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>10</td>
<td>188,0</td>
<td>85,28</td>
<td>54,64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>36.4</td>
<td>313,1</td>
<td>10</td>
<td>188,0</td>
<td>81,08</td>
<td>56,87</td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>10</td>
<td>188,0</td>
<td>85,50</td>
<td>54,52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Rd</td>
<td>54,64</td>
<td>Standard Deviation of Rd</td>
<td>1,32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>13.6</td>
<td>188,0</td>
<td>102,40</td>
<td>45,53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>36.7</td>
<td>297,5</td>
<td>13.6</td>
<td>188,0</td>
<td>102,80</td>
<td>45,32</td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>13.6</td>
<td>188,0</td>
<td>102,00</td>
<td>45,74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Rd</td>
<td>45,53</td>
<td>Standard Deviation of Rd</td>
<td>0,21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>6</td>
<td>188,0</td>
<td>92,44</td>
<td>50,83</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>36.6</td>
<td>312,8</td>
<td>6</td>
<td>188,0</td>
<td>85,69</td>
<td>54,42</td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>6</td>
<td>188,0</td>
<td>89,62</td>
<td>52,33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Rd</td>
<td>52,22</td>
<td>Standard Deviation of Rd</td>
<td>1,8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>6</td>
<td>188,0</td>
<td>98,95</td>
<td>47,37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>36.8</td>
<td>306,9</td>
<td>10</td>
<td>188,0</td>
<td>93,86</td>
<td>50,07</td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>10</td>
<td>188,0</td>
<td>93,74</td>
<td>50,14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Rd</td>
<td>50,07</td>
<td>Standard Deviation of Rd</td>
<td>1,58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>13.6</td>
<td>188,0</td>
<td>100,38</td>
<td>46,61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>37.1</td>
<td>308,7</td>
<td>13.6</td>
<td>188,0</td>
<td>98,96</td>
<td>47,36</td>
</tr>
<tr>
<td>H</td>
<td>31</td>
<td>3.2</td>
<td>13.6</td>
<td>188,0</td>
<td>98,48</td>
<td>47,62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Rd</td>
<td>47,36</td>
<td>Standard Deviation of Rd</td>
<td>0,5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Legend: De = Desired voltage, Um = Average voltage, Em = Average current, Resp = Splash and Al = Mass of electrode wire to be melted in 1 minute of testing.

Source: Murad et al., 2020.

Figure 5 shows the Rd values as a function of Vc. It can be seen that increasing Vc significantly reduces Rd. It is noted that there was a reduction of 20.22% when increasing Vc from 6 to 10 m/min, and a reduction of 20.08% when increasing from 10 to 13.6 m/min. The reductions in Rd are justified by the difficulty of forming a molten pool at higher Vc, as occurs when welding a weld bead. The objective here is to get small drops of metal deposited along the mill frieze. However, the greater Vc increases the difficulty of the drops adhering to the mill frieze, generating a greater amount of splash and, as a consequence, the
reduction of Rd. Such facts evidenced are similar to those observed by Sharma [1], in which the aspects quality and consequently sustainability are affected by Rd and these were influenced by Vc.

The results of the tests carried out for the clockwise and counterclockwise application direction and for the variation of Vc (6, 10 and 13.6 m/min), and in this it is noted that there was a reduction in Rd with increasing the speed at which the roughing is applied, regardless of the direction of rotation of the mill. Compared to the clockwise direction, the deposition yield was lower for Vc of 6, 10 and 13.6 m/min.

In relation to Um and Im, at Vc of 6, 10 and 13.6 the values obtained were similar to those found in the two variations in direction of rotation.

![Figure 5](image)

**Figure 5 – Results obtained with variation of Vc and direction of rotation**

Figures 6 to 8 present the voltage (V) and current (A) oscillograms as a function of time (T) for each Vc condition carried out in the field for the clockwise rotation directions. It is verified that the measured current values (Im) suffer a reduction with the increase in Vc and also that the peak-to-peak amplitude increases with the increase in Vc. These facts cause the splash generation to increase, reducing the Rd. New studies should be carried out in the future to explain this fact. This evidence is similar to that observed by Sharma [2] and, in addition to this, it was evidenced that this factor also influences sustainability results.
Figure 6 – Voltage and current oscillograms for 6 m/min and H

Source: Authors.

Figure 7 – Voltage and current oscillograms for 10 m/min and H

Source: Authors.

Figure 8 – Voltage and current oscillograms for 13.8 m/min and H

Source: Authors.

Figure 9 shows the aspects of the hard coatings applied to the mill frieze (teeth) for each of the Vc conditions, in which it is possible to visualize the changes in grain quantities and grain sizes. It is noted that the smaller Vc presented better Rd, and also presented grains of larger size and in greater quantities, characteristics desired for this application. Figure 10 shows the count of the amount of grain in an area of 4 cm², and in these two samples approved
There is no official standard adopted by companies for the quality control of this coating. Therefore, the criterion adopted for approval or disapproval of this coating is only the appearance. In this context, the engineer responsible for the roughcast application sector was asked to carry out his assessment. In this analysis, the tests with 6 and 10 m/min were approved and the application with 13.8 m/min was rejected, due to the small amount of material adhering to the mill teeth.

Figure 9 – Aspect of the hard coating obtained with variation in Vc.

Source: Authors.

Figure 10 – Quantity of grain obtained for 6 and 10 m/min

Source: Authors.

It can be seen in Figure 9, for Vc at 13.5 m/min, that the quality aspects of the hard coating obtained were not satisfactory, as the grains suffered a
significant reduction in their diameter. This fact demonstrates that the increase in Vc implies a drop in the desired quality, resulting in a large quantity of grains with dimensions smaller than those desired by the company. This result also resulted in a drop in the value of Rd.

It is verified, through these results, that the use of Vc of 6 m/min obtains an Rd of 65.69% compared to 54.64% of that used by the companies that manufacture this equipment (Vc = 10 m/min), that is, a 20.22% gain in the amount of material deposited, maintaining practically the same quality of application as the hard coating. However, there is a greater delay in application, that is, lower productivity. A cost analysis is necessary to justify the need for a decrease in Vc. This evidence is similar to that observed by Sharma [1], and this research adds that the influence on the quality aspect impacts sustainability.

A cost comparison was then analyzed, taking into account the costs related to the labor of the machine operator (average salary of R$2,500, that is, a cost of R$23.00/hour). The values relating to the costs of machines and equipment were not considered, as a specific analysis would only be possible based on data on machine times and times, depreciation values and other specific values according to the particularities of each company.

Considering that there was a gain in Rd of 20.22% (i.e. 65.69% obtained in this study compared to the 54.64% practiced by the company), it would be prudent to state that there could be a reduction in the number of passes to apply the same amount of material. Therefore, a correction factor (PF) of 20.22% was considered in the final value.

For cost calculations relating to the application of a mill with dimensions 1100 mm in diameter by 2200 mm in length containing 57 friezes, 5 hours are required as execution time (TE) for applying the coating, applying 10 to 12 crimp passes, with Vc of 10 m/min and 8 hours for Vc of 6 m/min. The raw material costs (MP) were presented according to the yield, that is, 60 kilograms for application with 10 m/min (Rd = 54.64%) and 26.68 kg for 6 m/min (Rd = 65.69%). And, finally, the value of R$ 15.00 per kilogram of wire was considered as the cost of raw material (MP). Table 4 presents these costs.
Table 4 – Cost of applying hard coating to a mill roll

<table>
<thead>
<tr>
<th>Vc (m/min)</th>
<th>TE (horas)</th>
<th>Custo M.O. (R$)</th>
<th>Rd (%)</th>
<th>MP (Kg)</th>
<th>FP</th>
<th>Custo MP (R$)</th>
<th>Custo Final (R$)</th>
<th>Custo Final + FP (R$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5</td>
<td>115,00</td>
<td>54,64</td>
<td>60</td>
<td>192,20</td>
<td>900,00</td>
<td>1015,00</td>
<td>1015,00</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>161,00</td>
<td>65,69</td>
<td>53,38</td>
<td>0</td>
<td>800,04</td>
<td>961,04</td>
<td>768,84</td>
</tr>
</tbody>
</table>

Savings per Mill Roll of R$ 246.16 (Reduction of 32%)

Legend: TE= execution time, M.O = labor, MP=raw material, FP=correction factor

Source: Authors.

The partner company carries out this work in approximately 1000 mills per year, the reduced cost would be R$ 246,160.00 per year. Also considering that approximately 4,000 mill rolls are used in Brazil, this savings would reach the value of R$ 984,640.00 per year.

If the same reasoning were extended to mill maintenance during harvest (coating application during operation) and we consider that 3.5 million kg of addition material are sold (amount provided by the input manufacturer), a gain in Rd of 20.22% the result would be savings of R$5,775,000.00.

Finally, the estimated gain for preparing the mill and maintaining the harvest would be approximately R$6,759,640.00 in Brazil.

This evidence is corroborated by Hill and Seabrook [4], who emphasize sustainability management under the Triple Bottom Line paradigm. The economic aspects obtained with the reduction of Vc contribute significantly with regard to sustainability parameters.

It is a fact that environmental aspects are not just limited to waste generation or energy efficiency. However, this study carried out an analysis considering only these two themes. Regarding the generation of waste, it must be considered here that the splash from the hard coating is destined for the sugarcane juice decanter, equipment that separates solid waste and this waste (filter cake) is final destined for sugarcane farming as a form of fertilizer. It should also be considered that this splash is considered a dangerous solid, according to Standard ABNT NBR 10.004, which deals with the classification of hazardous solid waste.

Based on the above, 3.5 million kg of filler metal are sold for hardfacing. And considering that all non-adhered addition material (splash material) becomes
waste that causes environmental impacts. It can be stated that a gain of 20.22% in Rd would reduce the generation of hazardous waste per year by 385,000 kg.

In relation to energy gain, following the same previous reasoning, in a simplified way it can be stated that a gain of 20.22% in Rd would result in a gain in energy efficiency.

3 CONCLUSION

Carrying out this work allowed us to reach the following conclusions:
- Applying the coating clockwise showed better Rd compared to counterclockwise.
- The reduction in the speed of roughing application during mill preparation resulted in a gain of 20.22% in deposition yield, that is, a reduction in the amount of wasted material.
- The lower Vc applied clockwise also resulted in a reduction in the final cost of preparing the mill for the harvest by approximately 32%. This was due to better deposition efficiency.
- The best condition for applying the splashback (lower Vc) obtained in this work leads to a reduction in the generation of 385,000 kg (splash material) of hazardous waste per year.

Finally, considering the economic and environmental pillars of the Triple Bottom Line, the reduction in application costs, electrical energy consumption and the generation without compromising the final quality of the hard coating contribute significantly to sustainability in production.

Responding to the hypothesis formulated in this research, the lower Vc for applying metallic coating showed greater RD and it was observed that the H direction demonstrated greater efficiency.

As a focus of this study, the analysis of the parameters Vc and direction of rotation was adopted as a sampling field, suggesting as a proposal for future work: a) analysis of other parameters such as welding current, DBCP, welding voltage among others; b) analysis of other types of filler metals present in the sulco-alcohol sector; c) analysis of other types of base metals present in the sugarcane sector, such as knives and hammers used in sugarcane preparation.
ACKNOWLEDGMENTS

The authors express their gratitude to the institutions that supported this work: Cefores/UFTM and UFU.
REFERENCES

[1] MURAD, M. Q.; FERRARESI, V. Application of chapisco in sugar cane milling with the fcwa process. 2015.


