Original Article

Development and application of a homemade procedure for manufacturing of mechanical spare parts

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Abstract

A homemade procedure for manufacturing of mechanical replacement parts was developed. The approach was applied to a guide ruler installed in machinery to produce steel rod frames. The guide ruler part, which is produced by the original manufacturer of the equipment, acts as an alignment guide of the steel wires. It ensures that the steel wires can be welded in the correct position so that the steel rod frames can be properly constructed. The guide ruler was selected due to its paramount importance for the proper functions of the equipment, the intensity of service loads, its high costs and poor availability. The methodology adopted for the homemade procedure was based on obtaining comparable chemical composition, microstructure and mechanical properties of the imported part. The main goal was to reduce the costs and delivery time for the acquisition of each spare part. The homemade procedure here used, however, is considered complete only after a comparison of the parts service performance and after an evaluation of the cost/benefit ratio. The results show that the studied part exhibited an increased economic efficiency in the equipment of about 83.0 percent, therefore its manufacturing in Brazil is viable.

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1. Introduction

Brazilian industries, especially the civil engineering and automotive one [1], have got a great dependence on importing tools and components for replacement due to Brazil’s lack of competitiveness and technological knowledge in machine tools manufacturing processes [2,3]. This problem of tool- and components-import dependence in Brazil may impose a significant operational cost as well as vulnerability to the
company due to possible logistic delays, which can compromise the company production healthy and decrease its profits. In this way, it is very strategic to develop systematic homemade procedures in Brazil.

Taking into account that spare parts (operational and maintenance) withstand recurrent mechanical stress, it might bring a big deal for the companies that work with imported machinery the replacement of these parts when they either suffer sudden anomalous behavior or reach their lifecycle (which is not always fully known). This can be explained by the fact that the procedure for acquiring new imported parts requires higher prices and time consuming than homemade ones. Indeed, the implementation of new homemade products might improve the product properties and lifecycle as well. In addition, eventual logistic issues might be minimized, besides the possibility of creation of technology and industrial matrix diversification in a big scenario. It is worthy to mention that works related to homemade procedures for manufacturing of mechanical replacing parts are very scarce in the technical literature, which makes this study of technological relevance at all.

Some authors have attempted to describe some procedures concerning the nationalization process for a significant amount of parts [1,4-6]. In such a way, the relevancy of spare parts on the equipment performance, its demand and amount of operational hours, as well as price and stock level has to be taken as the main criteria to select the parts that could be homemade manufactured. The main goal of this work is to develop a homemade methodology for manufacturing of mechanical spare parts, implement it to the ruler guide, and evaluate its performance. The guide ruler part is responsible for both guiding the steel wire and place it directly on the weld position so the rod frame can be properly built, as displayed in Fig. 1(a and b). Criteria such as similarity of chemical composition, microstructure and mechanical properties constitute the base of the developed methodology. It is intended to compare the properties above listed of the homemade manufactured part with the imported part and define the type of processing required (routes of heat and thermochemical treatment) to reach the best likeness and to develop available experimental database in case of sudden failure analysis of the homemade manufactured part. The performance and cost/benefit ratio are the most important parameters for deciding if the homemade procedure is viable.

2. Materials and methods

The investigated part is a ruler guide, which guide the wires in order to weld them, constructing steel rod frames, according to the Fig. 1(a and b). The sequences of activities that constitute the homemade methodology for manufacturing of mechanical spare parts are summarized and can be defined by two main steps: i) assessment of homemade procedure considering the similarity of chemical composition and microstructure; ii) definition of parameters for assessing material performance and cost/benefit ratio.

The ruler guide was present in commercial mechanical machinery. In this way, it was possible to use a comparable geometry for the homemade manufactured part, which was obtained from measuring the parts geometry of the machine in study [7]. The material was selected based on the working conditions and after a carefully investigation of the imported part chemical composition. Moreover, the requirements of the
original part were kept as reference for this study, which satisfied the classification adopted by the Brazilian Association of Technical Standards, which is in accordance with the criteria of the AISI-SAE (NBR 6006) system for the designation of several types of steel.

The chemical composition was determined by means of mass spectrometry using an Optical Emission Spectrometer device, ARL 3460 model Metals Analyzer, which provides a complete and reliable chemical analysis of metals, according to the standard testing [8,9]. The specimens were mounted in epoxy resin and ground using SiC abrasive paper down to 1200 grid and then polished using 1 μm diamond solution. The specimens for optical (OM) and scanning electron (SEM) microscopy were etched with 10% Nital reagent (nitric acid and methanol). The investigated specimens were characterized by means of conventional metallographic procedures. In this case, ten images were taken for each concerned condition to evaluate changes in the volume fraction of each phase (systematic manual point fraction counting), according to the standard test procedures [10].

Vickers hardness tests were performed using a load of 1.0 kgf on transversal sections of the specimens. Equations reported in the literature [11] were used in order to calculate the tensile stress from the hardness values. Ten indentations were made and the average was taken as the representative value for the material.

After confirming the appropriate geometry and manufacturing procedure of the homemade part, it was kept in the equipment for operation and assessment of its performance. The number of tested parts was equal or bigger than the number of variable that could influence their lifetime, i.e. the position in the equipment (in the case of parts with more than one specimen per equipment), some operational adjustments and the diameter of the raw product that is processed in the equipment. The reason for sudden anomalous behavior of the homemade manufactured part during the tests was identified and further investigated. Moreover, the main features for the homemade manufactured part, such as geometry, chemical composition, microstructure and mechanical properties were systematically analyzed.

The main parameters characterizing the part performance, such as intensity of abrasive wear, were treated independently in the investigation of the failure of the homemade manufactured parts. In this way, the experimental data from the imported parts was obtained in the beginning of the process and it was used as comparison for the homemade manufactured parts. Once the reasons for sudden anomalous behavior were detected, approaches to correct these problems were taken in order to ensure maximum performance of the part. In this case the original specification of the material, the mechanical loads imposed on the part during its operating in machinery and operational adjustments were respected.

Eq. (1) shows the $\eta$ index, which was developed during this study in order to investigate the feasibility of the homemade manufacturing process. The main variables, such as lifetime, diameter of steel wires, performance, cost/benefit ratio and shipping time were related in this index. The main failure mechanism has defined the end of the lifetime of each part and consequently the price of a tonne of produced steel. The homemade manufacturing process can be applied if the $\eta_s/\eta_i$ ratio, where subscripts $\eta_s$ and $\eta_i$ indicate homemade built and imported parts, respectively, was less than unity.

$$\eta = \frac{\cos t \times \text{deliverytime}}{\text{stettone}} \left[ \frac{\text{R}$ \times \text{months}}{\text{tonne}} \right]$$

(1)

The authors have proposed Eq. (1), also known as a figure of merit index, based on the criterion cost/benefit ratio.

3. Results and discussion

The DIN St 52 steel was the original material that was used by the supplier of the guide ruler part and it has the chemical composition listed in Table 1. It is a low carbon steel with addition of about 1.46 (in wt.%) manganese, which is in agreement with the literature [12,13].

Fig. 2 shows the optical microscopy (OM) micrograph of the DIN St 52 steel. The innermost region exhibits typical colonies of pearlite, highlighted in region A, surrounded by grains of proeutectoid ferrite, showed in region B. The measured pearlite volume fraction was around 0.24, with an error within 5%. The low volume fraction of pearlite is caused by the low carbon content and it leads to a not significantly pronounced wear resistance. However, it is important to mention that the presence of Mn in this steel improves the mechanical resistance and the hardness [13].

The ruler guide requires a minimum value of wear resistance in its upper surface in order to guide the upper steel rod during its operation. In order to join the rod frame, a thin electrode coating (1.50 mm in depth), known as UTP A SUPER DUR W 80 Ni, is placed on the entire upper surface of this imported part. Such electrode is suitable to be used on surfaces that require extreme friction and/or abrasive resistance. Fig. 3

Table 1 – Chemical composition of DIN St 52 steel (in wt.%).

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.21</td>
<td>0.319</td>
<td>1.46</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Fig. 2 – Microscopy optical micrographs of the innermost guide ruler cross section. DIN St 52 steel inhibiting grains of proeutectoid ferrite (B) and perlite colonies (A).
shows the interface between the coating thickness (showed in region D) and the innermost part (showed in region C) of imported guide ruler. Its profile hardness measurements and estimated tensile strength values are provided in Table 2. It is noticeable that the measured properties for the electrode are greater than those for the DIN St 52 steel.

On the other hand, the guide ruler must resist to the impact caused by the holder part (Fig. 1a and b) during its operation. In this way, its innermost part is designed to possess low tensile strength, which provides significant energy absorption during impact. Fig. 4 shows the contribution of both coating thickness and DIN St 52 steel on Vickers microhardness (and consequently, on the wear resistance) of the imported guide ruler.

Taking into account that the all minimum requirements were satisfied for an efficient performance, the imported guide ruler showed a fracture after 66 days of use. The crack has initiated at the internal sharp corner on the inside of the cavity, grew into the transversal section and ended at the bottom part. Such event indicates that the guide ruler has not achieved its maximum wear life (1.0 mm thick electrode coating) before the end of its lifetime. In this case, it was observed that the failure of the guide ruler has occurred after the electrode coating has been reduced merely 0.2 mm thick. Such event can be explained due to the highly localized stress at the internal sharp corner inside the cavity. As the guide ruler was held (as required) in place during its operation, the mechanical stress concentration at the internal sharp corner has led to crack nucleation and growth, which is highlighted in the transversal section in Fig. 5. Crack nucleation and propagation may have been favored due to the high hardness and, consequently, the high brittleness of electrode coating used on the guide ruler part.

In order to develop the homemade procedure for this part, the carbon steel selected was the SAC 300 steel, which is a low carbon killed-aluminum AISI-SAE 1012 steel with addition of around 1.09 (in wt.%) manganese and 1.140 (in wt.%),
Fig. 6 – Transversal section of the homemade manufactured guide ruler; (a) macrograph of the interface between the innermost part and the carburized surface; (b) optical and (c) scanning electron (scattered electrons imaging mode) image of the carburized surface.

Fig. 7 – Interface between the carburized surface and the innermost part of the homemade manufactured guide ruler.

Table 3 – Chemical composition of ASTM 1020 steel (in wt.%).

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.12</td>
<td>1.14</td>
<td>1.09</td>
<td>0.10</td>
</tr>
</tbody>
</table>

silicon, as shown in Table 3. The homemade manufactured guide ruler was machined and subjected to a surface liquid carburizing treatment in order to increase the hardness and consequently the wear resistance of the upper surface of the studied part.

Fig. 6(a) shows the interface between carburized surface and innermost part of homemade manufactured guide ruler. Carburized surfaces are harder than its bulk mainly due to the presence of the martensite phase, which is shown in Fig. 6(b and c). Besides the micrograph displayed in Fig. 6(b and c), the chemical composition performed in this work confirms that the homemade manufactured ruler guide is made of low carbon steel. In such a case, the microstructure, after quenching, is very well known as a fully martensite phase [14]. The amount of martensite that is generated decreases with the distance from the surface because the amount of carbon decreases with distance. Carbon, manganese and copper are added to improve strength and hardenability as well as retard the rate of softening of low/medium alloy steels whilst silicon retards and reduces the volume change to martensite [15].

It is the combined effect of all these alloying elements, heat treatment, and, to some extent, impurities that determine the property profile and, therefore, the performance of the carbon alloys steels used in the present work.

Fig. 7 shed lights on the amplified optical micrograph of the interface region. The microstructure basically consists on a ferritic matrix with a martensitic dispersion. The volume fraction gradient of ferrite and martensite promotes a
balanced combination of strength and ductility along the carburized surface. In this way, this region performance can be improved in order to prevent fatigue cracks or unsuitable hardness and/or wear resistance. Fig. 8 indicates that there is no martensite phase in the innermost region. This region has exhibited a mixture of ferrite and pearlite colonies (with a volume fraction of around 0.2 and an error within 5%), which is comparable with the imported guide ruler.

Hardness and tensile strength values were obtained along the transversal section of homemade manufactured guide ruler and are listed in Table 4. Fig. 9 exhibits the contribution of different phases on the Vickers microhardness (and consequently, on wear resistance) of the homemade manufactured guide ruler. Carburized surface has possessed a greater hardness than the electrode coating surface. In such manner, it can be deduced that the homemade manufactured guide ruler is suitable for its application.

Cracking failure has occurred in the homemade manufactured part after 63 days operation after 0.3 mm abrasion, which means that it occurred before achieving its maximum wear life e.g. 1.0 mm. In the same way of the imported part, the crack failure of the homemade manufactured part can be associated to the stress concentration associated to the sharp corner on the inside of its cavity.

Table 5 exhibits Eq. (1) and the parameters used to calculate \( \eta \) for each type of guide ruler. In this case, the cleavage considered the unique failure mechanism that defines the end of the useful life of each part. Table 6 summarizes the values of parameter \( \eta \) and \( \eta_i/\eta \) ratio.

Ferrite grain growth may have occurred in the innermost homemade manufactured part due to the employed temperature and carburizing time (930 °C/600 min), besides the coarsening of pearlite lamellae. However, the amount of Si and Mn that is added in the SAC 300 steel is greater than the amount of such elements in the DIN St 52 steel. Such fact apparently has maintained the microstructural aspects unchanged after the thermochemical treatment. In this way, the alloying elements may explain the increase in mechanical properties in innermost homemade manufactured part whose values are greater than the exhibited by the imported part. Even under such critical conditions the \( \eta_i/\eta \) ratio is less than one, which defines the homemade procedure as viable and their implementation into operation resulted in an annual economy saving of about 83.0% per equipment i.e. R$29,124.75 considering values and buy-prices of 2009.

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**Table 4 – Hardness values and tensile strength of the nationalized guide ruler.**

<table>
<thead>
<tr>
<th>Materials</th>
<th>Vickers microhardness, HV (HB)</th>
<th>Tensile strength, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI-SAE 1012 steel</td>
<td>234 (223)</td>
<td>750 [2]</td>
</tr>
<tr>
<td>Surface carburizing</td>
<td>382 and 402 (362 and 381)</td>
<td>1222 and 1286</td>
</tr>
<tr>
<td>Surface carburizing</td>
<td>690 (654)</td>
<td>209 [2]</td>
</tr>
</tbody>
</table>

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**Table 5 – Values that were taken as reference in order to calculate the parameter \( \eta \).**

<table>
<thead>
<tr>
<th>Guide ruler</th>
<th>Price/unit, R$</th>
<th>Useful life, dias</th>
<th>Amount of parts/year</th>
<th>Annual cost, R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imported part</td>
<td>6.326,97</td>
<td>66</td>
<td>365/66 = 5.53</td>
<td>5.53<em>6.326,97</em>1 = 34.990,10</td>
</tr>
<tr>
<td>Nacionalized correctly</td>
<td>1.026,37</td>
<td>63</td>
<td>365/63 = 5.8</td>
<td>5.8<em>1.026,37</em>1 = 5.865,32</td>
</tr>
</tbody>
</table>

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**Table 6 – Values of the parameter \( \eta \) for guide ruler parts.**

<table>
<thead>
<tr>
<th>Guide ruler</th>
<th>( \eta ), R$ × months/tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nationalized (n)</td>
<td>( \eta_i = 3.16 )</td>
</tr>
<tr>
<td>Imported (i)</td>
<td>( \eta_i = 625.4 )</td>
</tr>
<tr>
<td></td>
<td>( \eta_i/\eta_i = 0.005 )</td>
</tr>
</tbody>
</table>
4. Conclusions

(1) The homemade procedure for manufacturing of the guide ruler part has showed as a feasible process and the substitution of the imported part can result in an annual economy per equipment of about 83.0%, considering the data of 2009.

(2) The surface liquid carburizing treatment replacing the electrode coating showed to be a suitable and feasible procedure. The amount of removed material (prior to crack) from surface of both imported and homemade manufactured guide ruler was comparable during the same tested period of the equipment.

(3) Delivering time can decrease from 120 to 30 days considering the data from 2009 and the direct contact with national suppliers can be a very positive reason to implement the homemade manufactured guide ruler.

Conflicts of interest

The authors declare no conflicts of interest

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