Research Article

Tool wear analysis in milling of locomotives wheels

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Abstract

The present work aims to evaluate the tool wear during the milling process of locomotives wheels—class C. A digital microscope is used to identify both the wear and the damage. The wear or damage, when propagated, can compromise the wheel roughness, which has a significant economic importance to railroad maintenance. A system for image capture composed of an ISM-PM200S INSIZE Digital Microscope and the ISM-Pro software is used to measure the flank wear. Firstly, milling process is applied with different numbers of passes. The results showed that, after flank wear, the most common wear is the thermal crack. It is also possible to observe the appearance of chipping and fracture as a consequence of the combination of thermal and mechanical cracks in the same insert. The inserts are more damaged in the raceway, due to the hardening of this region during its use. Inserts in the frieze region also showed higher values of wear, justified by the conditions of the railway. The highest values observed are around 0.1 mm. It is possible to notice that some inserts showed other damages, such as breaks and chipping, even before reaching the end of life due to wear.

Keywords Milling · Rail wheels · Inserts wear

1 Introduction

The wheel is one of the most important components used on the railroad. They must be periodically inspected for possible or actual failures. The wheels are the most loaded components of railway vehicles and are subject to continuous wear. Framing the rolling profile of the wheels of the railway vehicle into the geometric and dimensional features, which are regulated by national and international norms and standards, is a key factor for traffic safety [4]. Defective or worn wheels to the limit are more likely to cause derailments, resulting in severe losses.

Figure 1 shows a cross section of the wheel rim, indicating the main details and parameters that are important for the performance of the wheels in service, such as frieze (A), rim (B), raceway (C), gauge point, baseline and diameter line ("tape" line). It is important to highlight the taper of the track through the 1:20 slope and the radius of agreement between the frieze and the track. The diameter of the wheel is measured in the section of the tape line [15].

The wheels are taken out of service and sent for maintenance when the dimensions of the frieze and rim reach the condemnation limits. The thin frieze, below 20,6 mm, can cause the frieze to break and increase the risk of derailment in curves. High frieze is a characteristic of excessive wear on the raceway and it causes damage to railroad switching devices. The vertical frieze is especially harmful to the direction of the wheel due to the loss of the taper of the track and the radius of agreement at the root of the frieze. It also causes damage to the switching devices. The rim height is related to the safety of the wheel in terms of mechanical and thermal stresses [15].

Since the worn train wheels immediately affect train operation—impacting on its quality and the service life

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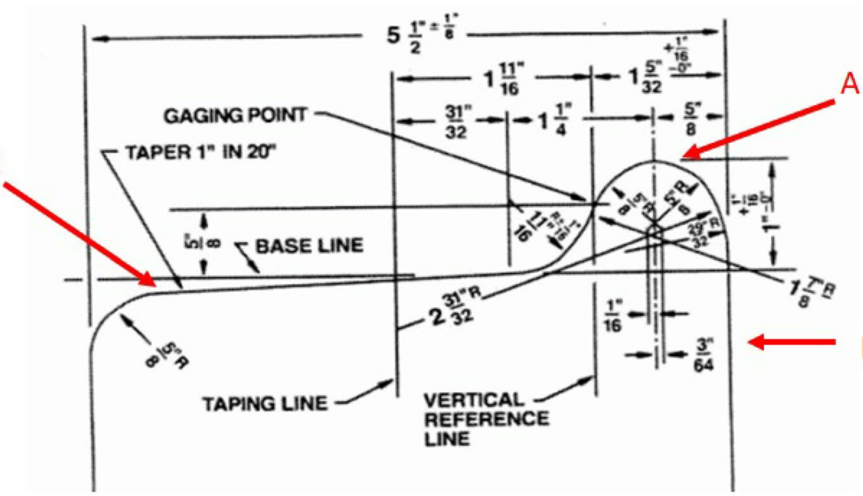
Fig. 1 Wheel cross section [5]



of rails—their reprofiling is considered to be an important to the maintenance of trains in service, although it is expensive [7].

Wheel recovery consists in the reprofiling process by machining it on a milling machine or lathe. This process redoes the contours of the wheels on the wheels by removing material. After the process, the shape and dimensions of the original profile of the rim contours are recovered. As a consequence, the diameter of the wheels is decreased by reducing the thickness of the rims. The use of milling and lathes ensures that symmetrical wheels are obtained after the operation.

Reprofiling the wheel tread profile is an important and large-scale manufacturing challenge. Both in milling and turning, the cutting tool is a key element that ensures both the efficiency and the reliability of the manufacturing process[2].

During the reprofiling process, the inserts are exposed to different conditions, depending on the type of wear of the wheel, directly interfering in its wear, which can lead to the fracture of the insert. Figure 2 shows the main faults to which the cutting tools are subjected.

Often, the definition of the tool's end of life is made visually, by the operator himself. Given the difficulty in establishing the end of life, it can be done conservatively, to avoid damage to the wheel, or contrarily, prolonging the use of the tool even after the end of life,

Fig. 2 Wear and tear in cutting tools [13]

which can lead to increased machining force and also the roughness of the wheel.

Extensive research has been conducted on wheel tread. Alexey et al. [2] showed that the most common mechanism of failure is the brittle fracture of the cutting edges, such as macrochipping on the rake and flank faces of the carbide inserts. They also noticed that the highest rate of inserts wear was registered in the area of the raceway.

Jianxi Wang, Xin Xue and Yongjie Lu [7] conclude on their paper that, once "serrated chip" occurs, it means that wheel tread machining quality deterioration dramatic, so it is important to avoid "serrated chip."

This study uses a system of image capture composed of an ISM-PM200S INSIZE Digital Microscope and the ISM-Pro software to identify and measure wear and damage in the inserts used in the milling of the railway wheels at the Milling Machine of Malha Sudeste Regional (MRS) Logistics S.A. in Santos Dumont- Brazil. From this evaluation, it is intended to define the region of the wheel where insert wear is more accentuated, as well as assess the evolution of wear and damage of tools.

The work in question is structured in 4 sections, including the introduction. The second section comprises the materials and methods that deals with the methodology used; The third section deals with the results and the relevant discussions. Lastly, the final considerations of the study are presented..

Fig. 3 Kawasaki milling machine

2 Materials and methods

2.1 Milling machine

The 1979 Kawasaki milling machine, represented by Figs. 3 and 4, is located in an underground level of the MRS Logistics S.A. workshop in Santos Dumont. It has two spindles that profile the two wheels of the axel at the same time.

The wheels are milled without being removed from the locomotives, as shown in Fig. 5, which saves time and stock of wheels.

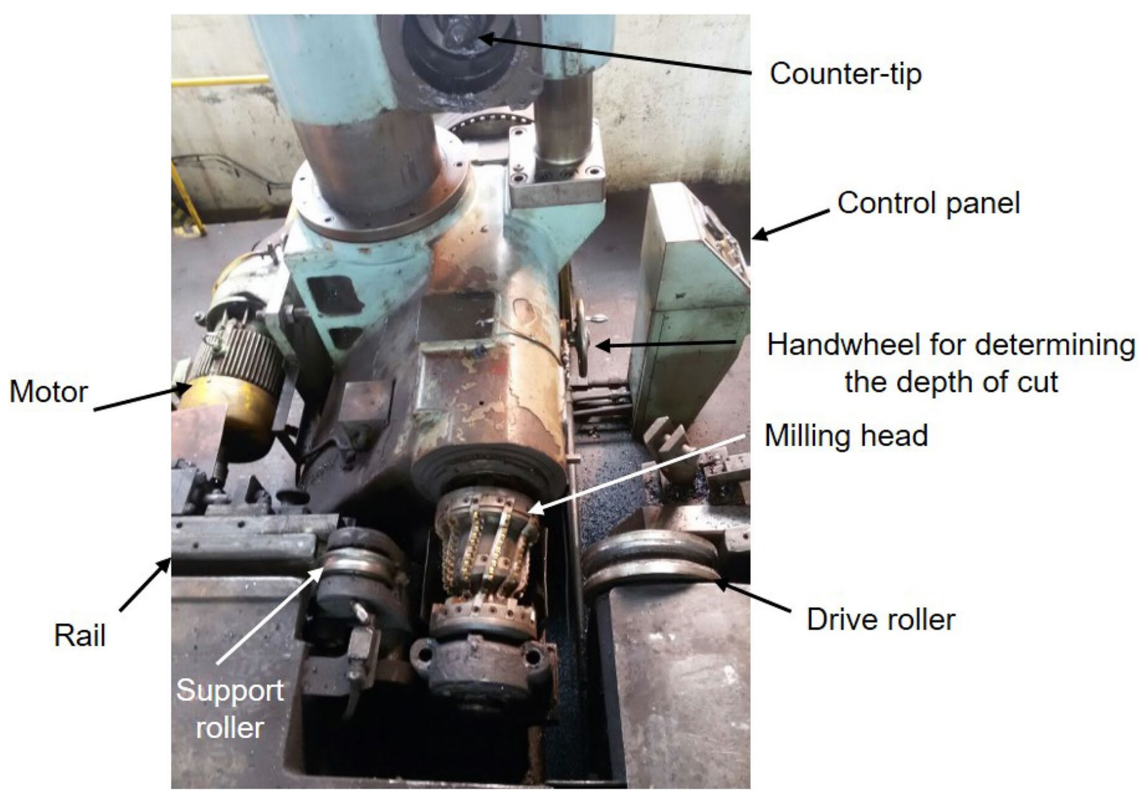


Fig. 4 Kawasaki milling machine top view

Fig. 5 Locomotive positioned for milling

MRS milling machine in Santos Dumont works with a discordant milling process, where the tangential speed of the cutter has a direction contrary to the forward movement of the wheel. In this type of milling, there are excessive friction and high temperatures, greatly encouraging tool wear. In addition, the milled surface produces undesirable vibrations, which impair the surface finish and tolerance of the milled part [6].

The rail wheel cutter consists in a head with the wheel profile (Fig. 6), where 150 cutting inserts are positioned, which are divided into 10 combs with 15 cutting tools each. MRS currently uses N221526152 inserts, produced specifically for milling these wheels. The inserts are composed of a WC–Co carbide (cermet) with Ti, S, Nb and a Ti coating. Two wheels are milled at the same time, by two identical heads. During the milling process, the heads approach both wheels simultaneously, as determined by the operator.

2.2 Parameters

For correct determination of wear on the inserts, some parameters were fixed. Firstly, the locomotive model that would have the milled wheels analysed, and the model AC44, which is the most used by the company, were defined. Counting with forged wheels.

The wheels in question belong to class C, through Specifications M-107 (AAR) composed of steel with a ferritic-pearlitic structure, in which a specific chemical composition is determined, as shown in Table 1 below.

According to specifications, for class C wheels, the hardness is between 321–363 HB and 30–42 HRC [1].

The feed (f) and working depth (ae) used assume values equal to 350 mm / min and 2 mm, respectively. The rotation was set at 150 rpm. The milling process is carried out dry. Each wheel is approximately forty-two inches in diameter, so the cut length of each pass is about 1060 mm.

2.3 Wear monitoring

As the study took place in an important recovery process for MRS wheelsets, it was necessary to adapt the analysis

Fig. 6 Head

Table 1 Chemical composition according to the AAR standard for railway wheels [1]

C	Mn	Si	P	S	Cr	Ni	Mo	Al	V	Nb
067–0.77	0.6–0.9	0.15–1.0	0.3 max	0.005–0.04	0.25 max	0.25max	0.1 max	0.06 max	0.04 max	0.05 max

Table 2 Number of passes per sample

Samples	1	2	3	4	5	6	7
Number of passes	1	2	3	4	7	18	34

Table 3 Measurement details

Zoom	Focal distance	Field of vision	Accuracy
50 x	21 mm	8.1 × 6.4 mm	30 µm
100 x	13 mm	3.9 × 3.1 mm	15 µm
150 x	16 mm	2.6 × 2.1 mm	10 µm
200 x	19 mm	1.8 × 1.5 mm	8 µm

to the company's production cycle, in order to avoid time-wasting at most. Thus, at the beginning of the shift, the milling heads were prepared with new inserts. To monitor the wear of the inserts, the samples were taken as indicated by Table 2.

The number of passes was defined according to the number required by wheels, that is, after the fourth pass, one wheel was completed. Sample 5 was used for machining two wheels, sample six three wheels and sample seven for four wheels. The values are not directly proportional, as they depend on the state of the wheels.

It is important to notice that each sample did not return to the machine after the measurement, i.e., the first inserts machined a pass on one wheel, the second sample machined two passes on another wheel and it went like this until the seventh sample, which machined 34 passes before being removed for analysis, always starting with new inserts.

With the inserts collected, the type of wear or damage was first assessed and the result recorded on a spreadsheet.

Wear measurements were performed by a system for image capture composed of an ISM-PM200S INSIZE Digital Microscope and the ISM-Pro software. The details of the measurement is shown in Table 3.

No replicas were performed due to the difficulty of interrupting the company's production process. The measurements were performed considering ISO 3685 standard given by the width of the maximum flank wear (VBmáx). Figure 7 shows the flow of the process.

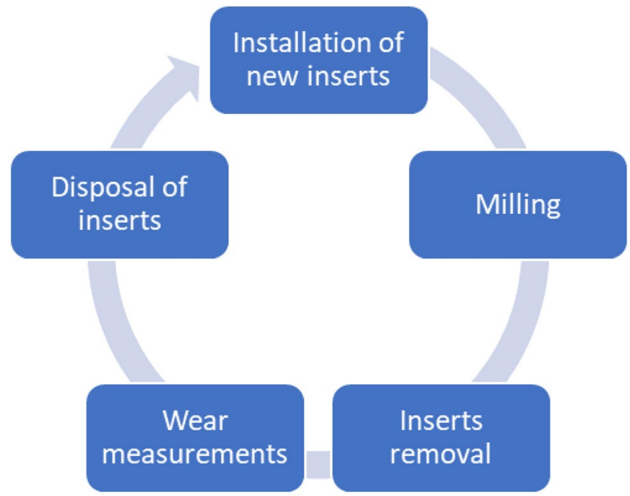


Fig. 7 Flow chart of the process

3 Results and discussion

3.1 Wear evaluation

The first observation of the inserts, right after the first pass, revealed that not all the inserts touched the wheel, showing no wear values (Fig. 8). The wheel had high and thick frieze characteristics. Due to these characteristics, it was not possible for the entire wheel profile to have contact with the tool.

In this analysis, a premature chipping of the insert at position 2 was noticed, as can be seen in Fig. 9. According to Lopes [8], the contact stresses resulting from the mechanical efforts of the wheel against the rail lead to the metal hardening in the wheel surface, which can be defined as its hardening by plastic deformation. This increase in hardness associated with calluses and raceway imperfections may have resulted in increased cut resistance with the consequent chipping of the cutting edge of the tool.

The other inserts that came into contact with the part showed flank wear. The measured values are shown in Fig. 8. The hypothesis of increased hardness due to hardening is reinforced due to the more prominent wear perceived in position 3, next to the one that showed chipping. Inserts 12, 13 and 14, which had contact with the frieze, also showed wear. Due to chipping, it was not necessary to measure wear of insert 2, although it certainly occurred.

The second observation collected inserts that worked two passes. The wheel had a high frieze characteristic. Not all inserts have had contact with the wheel yet, but, compared to the first observation, more inserts came into contact with this part, given the vast amount of material removed. Wear values were recorded (Fig. 10). The inserts that came into contact with the part showed flank wear.

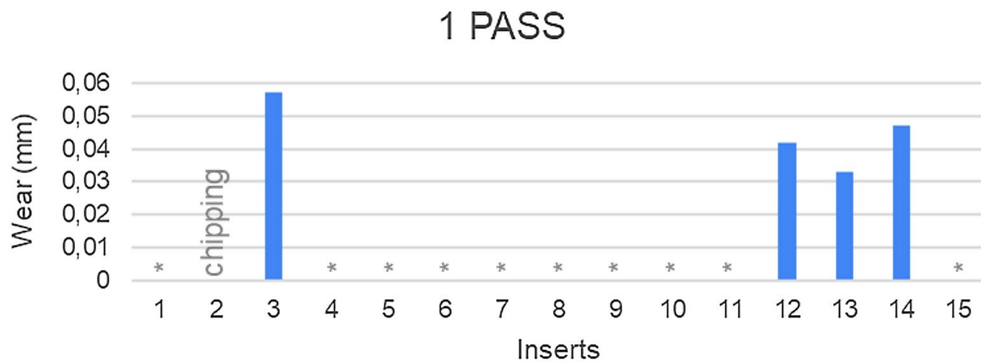


Fig. 8 Graph of wear with one pass (for * no wear values)

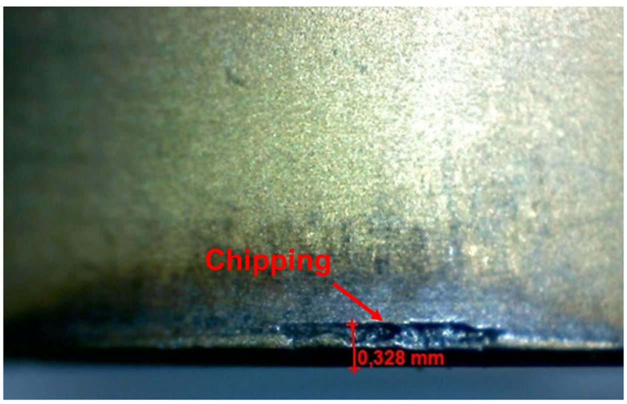
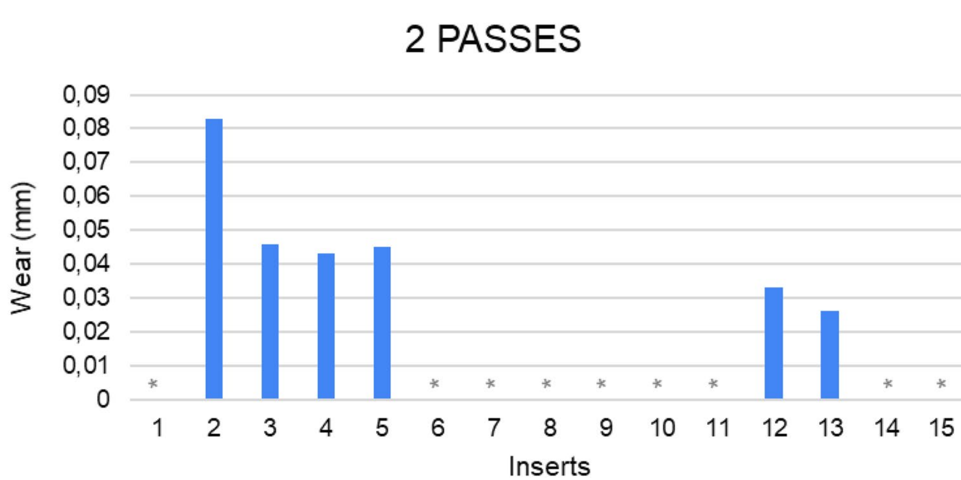


Fig. 9 Chipping in the insert 2 (expanded 100X)

The measurement results (Fig. 10) show wear in the crimp region (positions 12 and 13) and at the beginning of the raceway (positions 2, 3, 4 and 5). Due to the practice of lubricating the rails, friezes wear is reduced, especially in curves. Therefore, many wheels will have high friezes when recovered. This region ends up having more contact with the tool. Due to the complex geometry of the milling head, not all regions touch the wheel equally from the beginning of milling. Point 2, also on the wheel's raceway presented a high wear too. It is the same one that showed chipping in the previous observation. Due to the characteristics of the railroad where this locomotive travels, this region of the wheel has little wear. MRS manages 1,674 km of railways and its route has a large extension in curves of medium or small radius. Centro Line, for example, has 58% of its length formed by curves up to 300 m in radius [14]. Again, it is clear that the region at the beginning of the raceway caused more wear on the tools, even with insert 2 showing more accentuated wear. According to Chaves [3] by comparing the hardness profile of the raceway with the friezes, it is possible to observe that in the raceway a greater hardening occurred when compared to the flange.

Insert 2 deserves greater attention, given that it presented flank wear, thermal and mechanical cracks, as can be seen in Fig. 11. The practice of not using cutting fluid when milling occurs precisely to reduce the risks of thermal cracks, however the milling process, due to intermittent cutting, can cause these defects in the tools. In this

Fig. 10 Wear graph with two passes (for * no wear values)



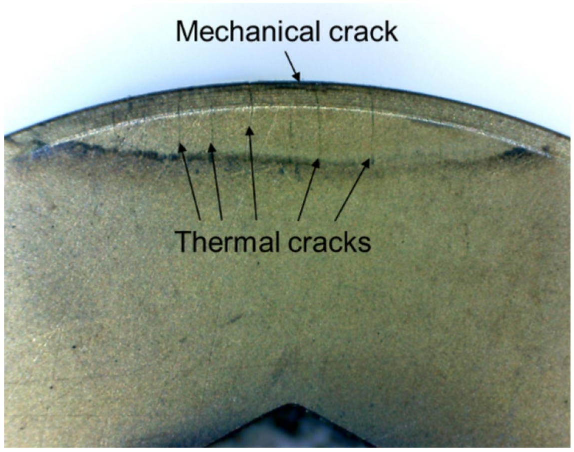


Fig. 11 Insert 2 with thermal cracks (expanded 80X)

process, in the first passes, the tool is faced with a material with high hardness due to hardening by hardening the wheel, consequently, the forces needed for cutting are greater, so mechanical cracks were also found.

In the third observation, after three passes, the wheel also had high and thick frieze characteristics. Once again, the number of inserts that came into contact with the piece was greater than in previous passes, as shown in Fig. 12.

The inserts that came into contact with the part showed flank wear. At this point, it is possible to observe in Fig. 12 that most of the inserts came into contact with the wheel. The inserts have very close flank wear values, given that the difference in measurements between the tools with the highest and lowest wear is less than 0,02 mm. It happened because at the beginning of the cut the efforts are bigger, so that wear grows quickly. Afterward, wear tends to an almost constant value before it grows again and fails [16].

In sample 4, with the exception of the insert in position 7, Fig. 13, which suffered chipping, and inserts 14 and 15, that didn't-wear, all the others showed flank wear. Near the region that showed chipping, it is possible to notice a crack that appears to be of mechanical origin. Looking at Fig. 13b, which represents the rake surface of the same insert, it is possible to notice a small crack of thermal origin. According to Melo et al. [10], the meeting of the mechanical cracks with the thermal cracks leads to detachment of portions of the cutting edge, accelerating tool wear.

It was not possible to measure the wear of insert 7. According to Fig. 14, the number 1 insert suffered the greatest wear, in addition to, possibly, that of position 7, where the chipping occurred.

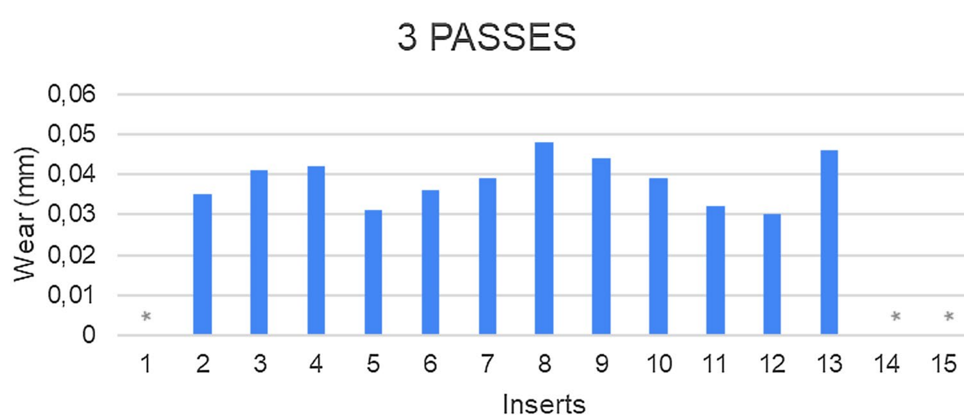
In the fifth analysis, the inserts that machined for 7 consecutive passes were observed. It can be seen in wear measurement, represented by Fig. 15, that tools wear that machine the raceway was greater than the others. Comparing with the samples from the previous observation, it is noted that the average wear, considering only the tools that cut in both cases, was 0,0389 mm for 4 passes and 0,0454 mm for 7 passes, an increase of 16,7%, that is, tool degradation due to friction is occurring. Although the region formed by tools 11, 12, 13, 14 and 15 are those that remove the largest amount of material, it is not the one that presents the greatest wear.

Inserts 14 and 15, due to the geometry of the wheels machined in this stage, did not cut, so they did not show wear. Insert 1 showed chipping, Fig. 16, so wear measurement was not possible.

The cause of this chipping may be related to what has already been mentioned, the hardening of the region of the track and the thermal cracks common in the milling process. Figure 17 shows some cracks perpendicular to the cutting edge on the rake surface of this insert, generally identified as thermal cracks.

With 18 passes, in the sixth observation, six inserts showed chipping. Thus, as shown in Fig. 18, it was not possible to measure these tools wear, along with number 14 and 15 (which did not touch the wheel). Wear continues to evolve on the other inserts, reaching

Fig. 12 Wear chart with three passes (for * no wear values)



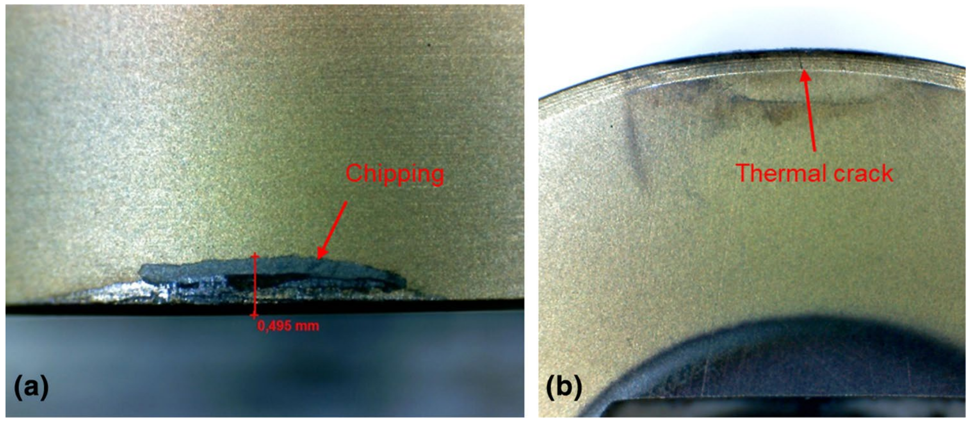


Fig. 13 Insert 7 for 4 passes (expanded 80X). **a** Chipping and mechanical cracking; **b** Thermal crack

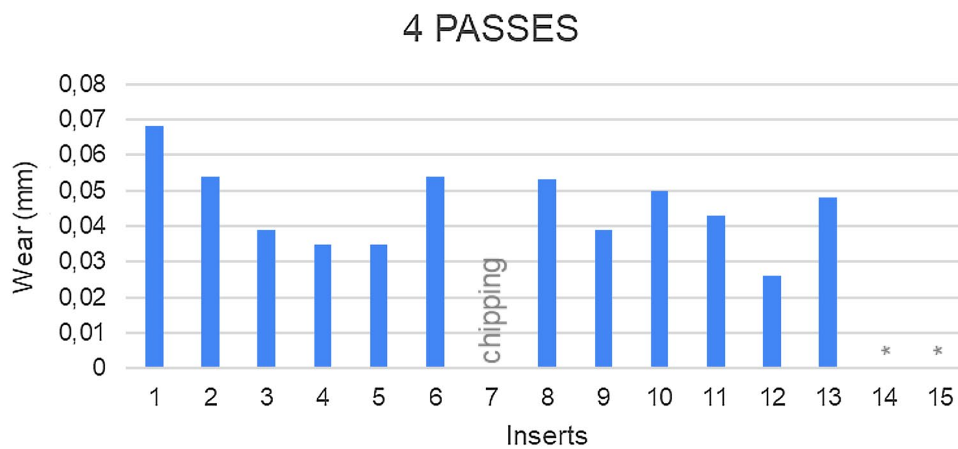


Fig. 14 Wear chart with four passes (for * no wear values)

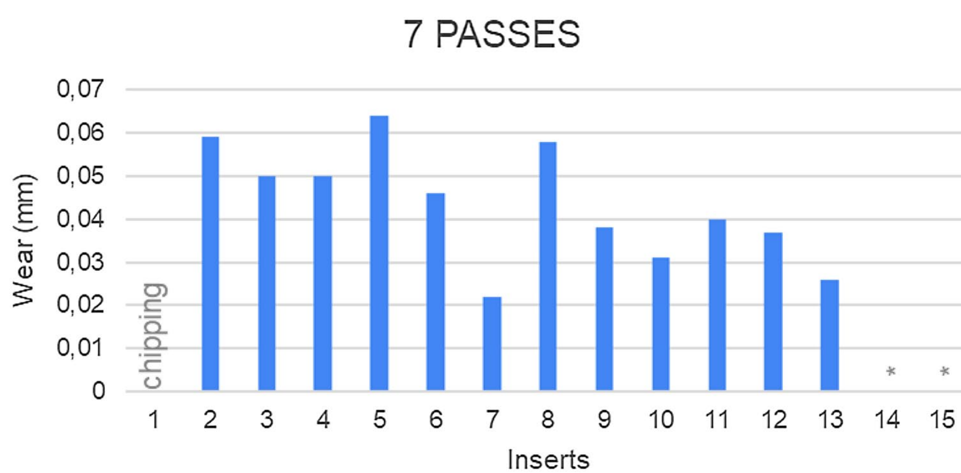


Fig. 15 Wear chart with seven passes (for * no wear values)

approximately 0,1 mm for insert 1 and above 0,05 mm for other 4 inserts.

Inserts 3 and 4, Figs. 19 and 20, respectively, did not have wear measurement performed because they showed chipping. The mechanisms described above that involve hardening and cracks may have been influential for this occurrence.

Inserts 5, 8 and 9, Figs. 21, 22 and 23, respectively, had-a more protuberant chipping that elongated to the tool's rake surface and originated what can be classified as a fracture. It was also not possible to measure wear. These damages may have occurred by the same mechanisms discussed as well as due to high wear, considering that 18 consecutive passes have already passed. According to

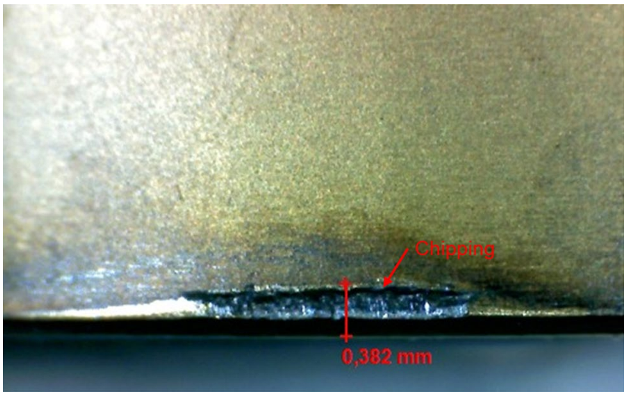


Fig. 16 Clearance surface of insert 1 after 7 passes (expanded 100X)

Fig. 17 Rake surface of insert 1 after 7 passes (expanded 80X)

Picarelli [12], tool wear leads to a continuous increase in cutting forces and ends up causing it to break.

After 34 passes, with the seventh analysis, wear measurement shown in Fig. 24 was obtained. Despite the high number of consecutive passes, only the address tool 2 showed chipping. Insert 15 did not perform machining.

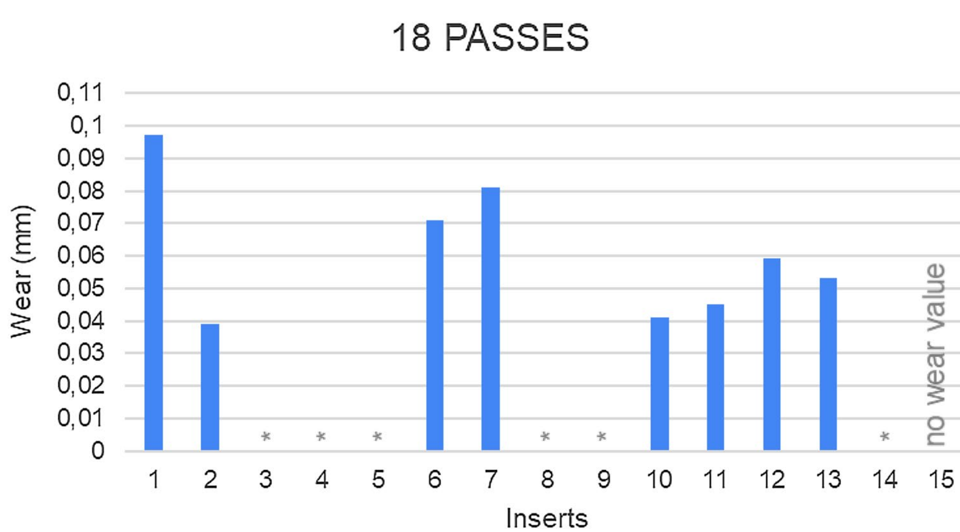
The average wear of the inserts that performed machining with 34 passes was 0,049 mm, almost the same identified after 18 passes. According to Machado [9], the evolution of tool wear goes through three stages: the first shows rapid wear evolution, as well as the last, while in the intermediate period there is a less accentuated wear rate. This theory was confirmed experimentally by Mesquita and Barbosa [11], who present Fig. 25, which shows a more central region of each of wear curves for tools when milling two types of steel. Between 18 and 34 passes some of the inserts may have reached this region of wear stability.

The fact that some inserts showed premature chipping can be explained by variations in the state of the machined wheels. In addition, the profile of the milling head is quite complex, since it must accompany the wheel profile. Therefore, although the rotation is the same for all inserts, some are located in different diameters. Consequently, they work with different cutting speeds, which significantly interferes in the mechanisms of wear and damage.

With 34 passes, even some inserts that did not show chipping had thermal cracks clearly visible on the exit surface, as can be seen in Fig. 26. Cracks of thermal origin seem to be the main causes of chipping in the cutting tools.

Figure 27 represents the average of wear measurements found in each analysis. As it was expected, the average value of the expenditure increased in almost all observations. In addition, when using coated carbide tools, wear grows slowly, firstly due to coating resistance, but after

Fig. 18 Wear chart with eighteen passes (for * chipping or fracture)



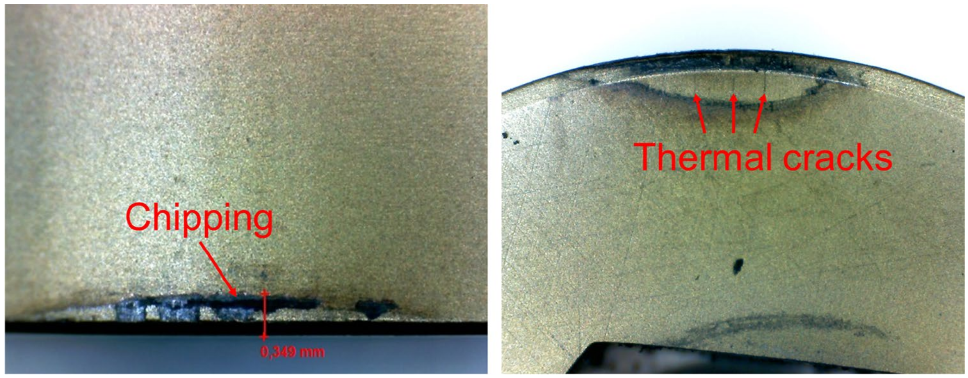


Fig. 19 Clearance surface and rake to insert 3 after 18 passes (expanded 80x)

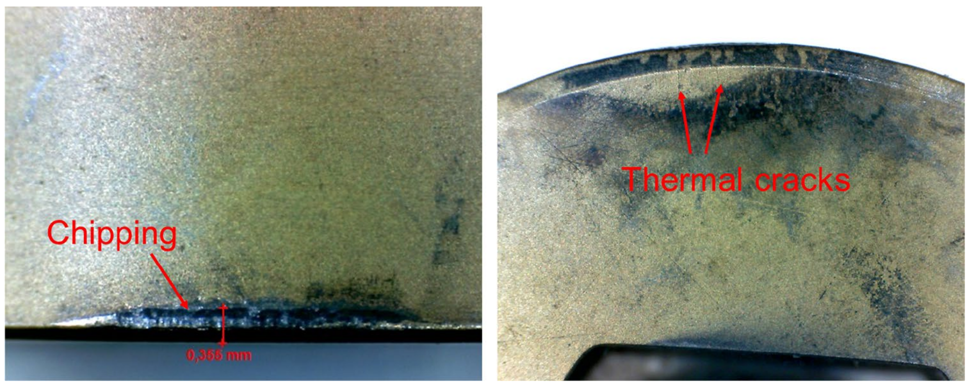


Fig. 20 Clearance surface and rake to insert 4 after 18 passes (expanded 80x)

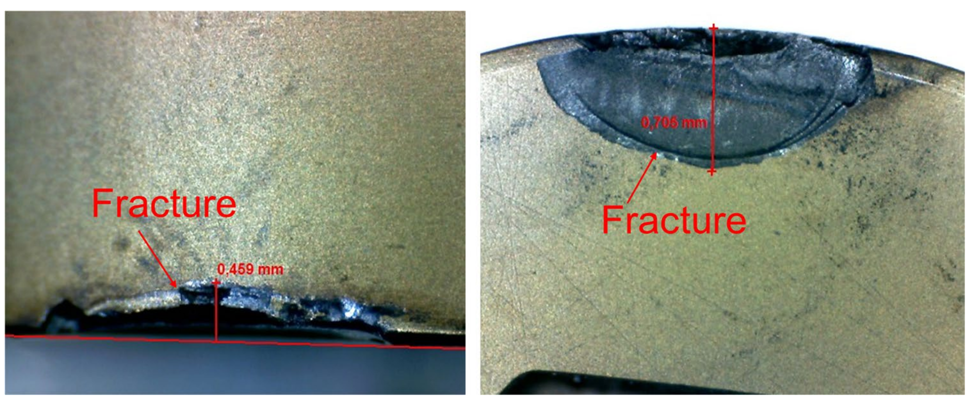


Fig. 21 Clearance surface and rake to insert 5 after 18 passes (expanded 80x)

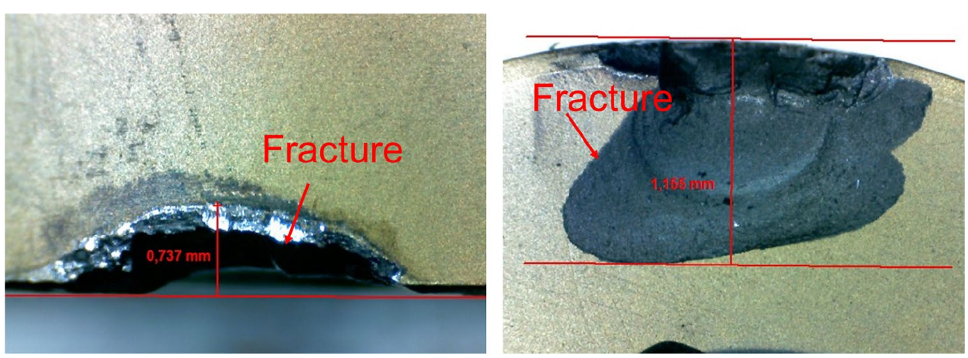


Fig. 22 Clearance surface and rake to insert 8 after 18 passes (expanded 80x)

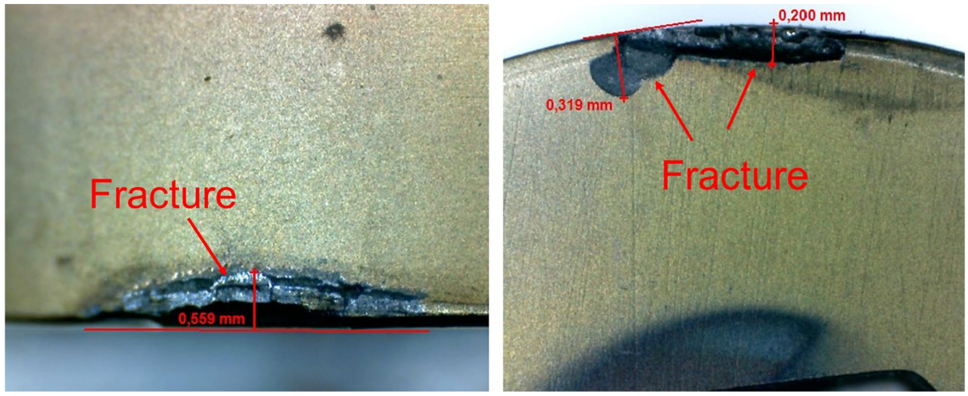


Fig. 23 Clearance surface and rake to insert 9 after 18 passes (expanded 80x)

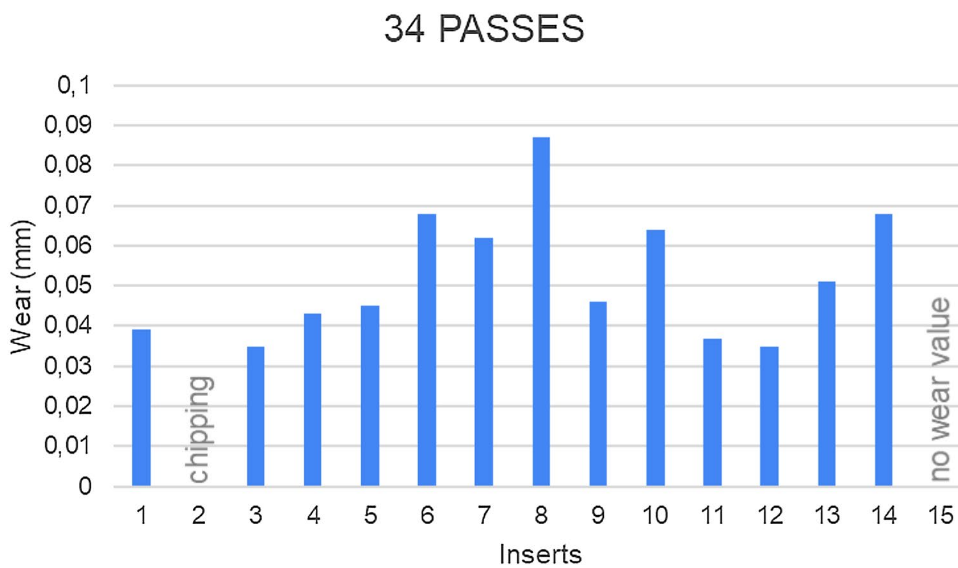


Fig. 24 Wear chart with thirty four passes

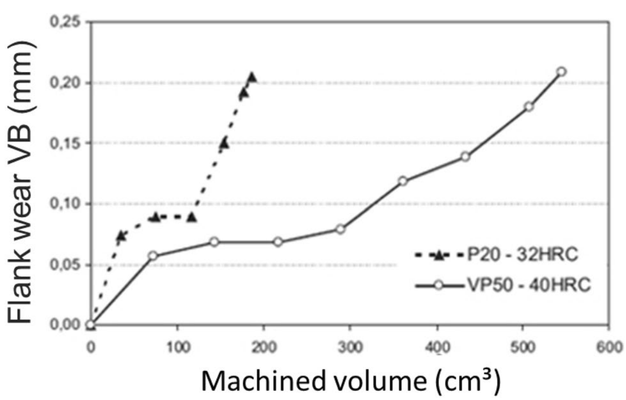


Fig. 25 Results from milling two steels with different hardness [11]

reaching high wear values (VB), the coating layers are almost completely consumed and the substrate is less resistant, it is exposed to the process, considerably increasing wear and tear, which can lead to breakage [16].

4 Conclusion

The objective of the study was to evaluate wear and / or damage to the inserts used in the milling of the railway wheels. Consequently it was analysed which part of the wheel generates more wear on the inserts.

The first results showed that, after flank wear, the most common one was a thermal crack, which proved to be one of the main reasons for chipping and fracture of tools. Even though the insert has elements in its composition that increase thermal resistance, such as S, this was not enough. A possible solution to this problem could be changing the composition of the insert, so as to increase its resistance to temperature.

In addition, it was observed that the region where there was the greatest wear of the inserts occurs is the raceway one. This is justified by the fact that this region is in contact with the track for a longer period increasing the hardness of the wheel. Inserts in the frieze region

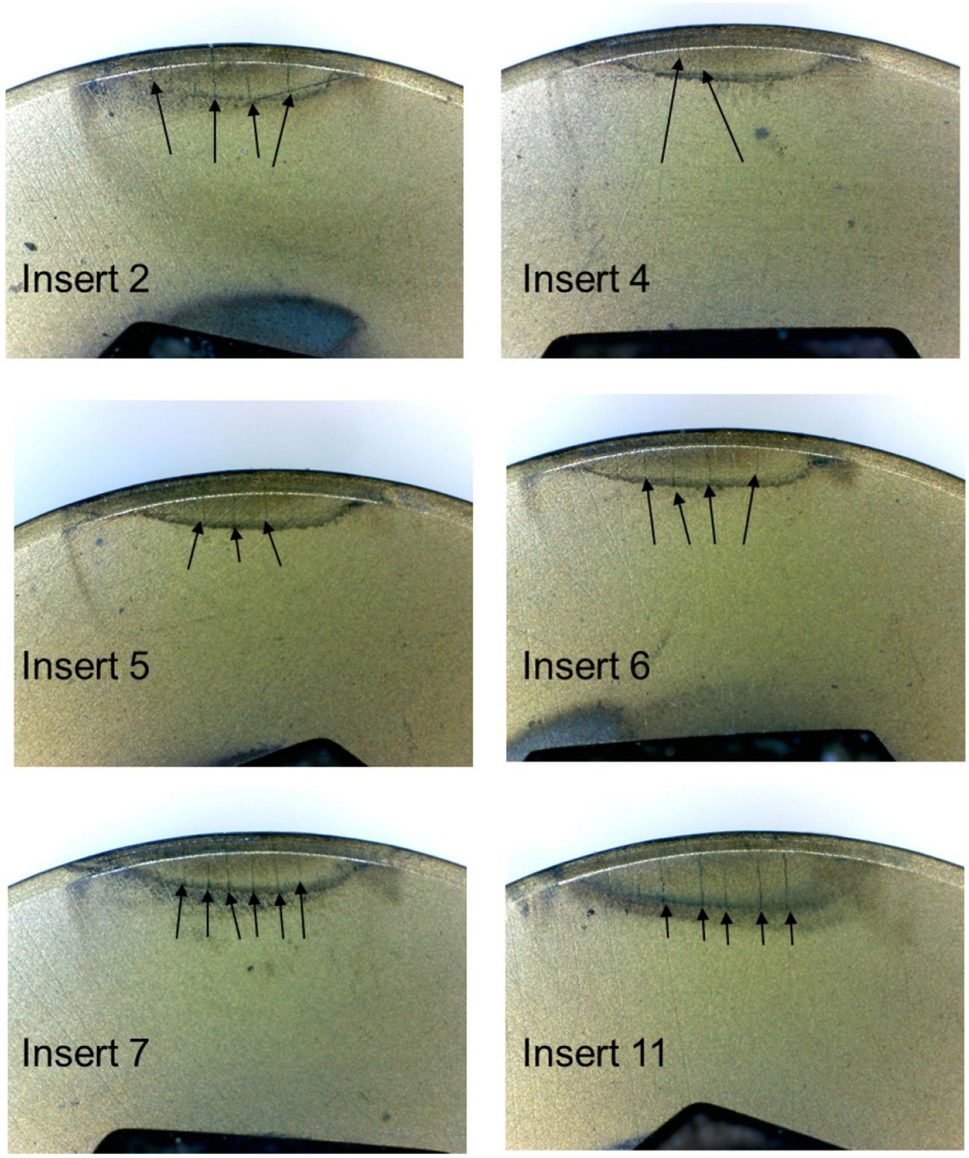


Fig. 26 Rake surface of some inserts after 34 passes (expanded 70x)

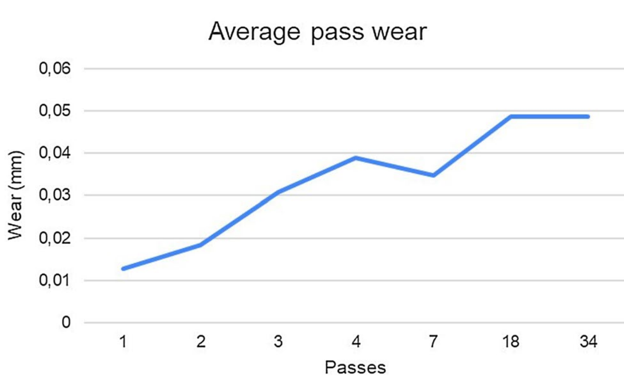


Fig. 27 Average wear per pass

also showed higher values of wear, but in this case, wear is justified by a large amount of machined material, due to the conditions of the railway through which the trains under analysis provide the presence of high and thick frieze.

The results pointed to the behaviour that was expected, that is, it was increasing and proportional to the cut length covered. The highest values observed are around 0.1 mm. It was possible to notice that some inserts showed other damages, such as breaks and chipping, even before reaching the end of life due to wear.

Therefore, it can be concluded that the inserts in the scroll region suffer wear the most. In addition, a possible solution to the emergence of thermal cracks would be the adoption of inserts with greater resistance to temperature. A suggestion for future work is the evaluation of inserts with different compositions to analyze the resistance to the appearance of thermal cracks.

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Availability of data and materials All the data is available in the present paper.

Code availability Not applicable.

Compliance with ethical standards

Conflicts of interest Authors declares that they have no conflict of interest with the topic addressed.

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