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EVALUATION OF THE BEHAVIOR OF WORN OUT RAILWAY COMPONENTS OF THE SHOCK AND TRACTION SYSTEM THAT ARE RECOVERED BY WELDING

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Abstract. *The main cast components of the shock and traction system (coupler, yoke and drawbar) on heavy haul wagons (GDT / GDU / HAT) are limited to 12 years of use, even if approved in inspection, due to the higher probability of presenting fatigue cracks. The objective of this research is to evaluate the possibility of extending the useful life of this equipment. The methodology presented in this project is to conduct laboratory tests of fatigue, tensile strength, hardness, and metallographic analysis, comparing four conditions for the components: new, used, recovered by means of welding, and recovered by welding with heat treatment. The results showed that the new and used parts presented good results and those recovered by welding without heat treatment showed a very fragile microstructure called Widmanstätten Ferrite. Finally, the samples that were recovered and treated showed high hardness values, whereas the values measured for elongation and reduction in area in the tensile tests were low. Therefore, it was concluded that the tempering temperature was low and the temperature of 560°C was the most adequate to achieve the purpose of increasing the useful life of these components.*

Keywords: *Heavy haul, Shock and Traction System, Welding.*

1. INTRODUCTION

The cast components of the shock and traction system (coupler, yoke and drawbar) in heavy freight wagons (GDT / GDU / HAT) undergo great repetitive stresses, which limits their useful life to 12 years, even if approved in workshop inspection, due to their greater susceptibility to show cracking as a result of fatigue. To predict the behavior of these materials if they were subjected to longer use, some tests have to be performed. As these materials are subjected to many mechanical stresses, the suitable tests are for fatigue, tensile strength, hardness, and metallography. The samples provided by a company partnering with the Federal University of Juiz de Fora (UFJF) were presented four different conditions, these being one material that was new, one worn out with 12 years or more of use, one worn out and recovered by welding without heat treatment, and one worn out and recovered by welding with heat treatment.

2. METHODOLOGY

The methodology used in this project was the selection of worn out samples with more than 12 years of use, which were recovered by welding. After this process, they were machined to the original dimensions of the casting and then treated completely by quenching and tempering. According to the AAR (2005) definition, non-destructive magnetic particle and hardness tests were run and specimens were removed from the welded regions using a cooled band saw to conduct fatigue, hardness, tensile, and metallographic tests. Finally, samples were tempered at higher temperatures to analyze their behavior. All the tests except recovery by welding, done at a company that develops this process for the partner company, were carried out in the laboratories of the Department of Production and Mechanical Engineering of the Federal University of Juiz de Fora.

2.1 Withdrawal of samples

The samples were cut and properly identified in the UFJF laboratories, using a horizontal cooled band saw to avoid heating of the parts and consequent changes in their properties. Figure 1 shows the saw.

Figure 1. Horizontal cooled band saw for metals.
Available from: https://www.lojadomecanico.com.br/produto/85825/21/224/

To carry out the tests, the samples were taken from regions recovered by welding. Figures 2 and 3 show the location where the samples were removed.

Figure 2. Specimens material cutting regions in the drawbars.

Figure 3. Specimens material cutting regions in the yoke with heat treatment.

After cutting, the specimens were machined for fatigue and tensile test.

Figure 4. Test specimens obtained from conventional lathe and CNC lathe for the fatigue test.

2.2 Fatigue Testing

The fatigue test was performed using bi-supported rotary bar type equipment in accordance with ASTM A370-14 (2014) and Reed-Hill (1982). Figure 5 shows the equipment.

Figure 5. The rotary fatigue machine. Available from:
http://www.novadidacta.com.br/produtos-categoria-produto.php?id_cate=11&id_sub=110&id_prod=408

Tension was determined using as the basis a recent study (Alves *et al.*, 2015) in which the worst maximum tension condition for these same components was 210 MPa. A safety factor of 30% was applied so that the tests were done with a tension of about 273 MPa. The tests were carried out until reaching infinite life, with more than 10^6 cycles (Juvinall and Marshek, 2008) and (Budynas and Nisbett, 2011).

2.3 Hardness test

The hardness test performed was the Rockwell C according to ASTM E18-15 (2015). Twenty-two measurements were performed, spaced at 3.0 mm in the longitudinal direction of the samples. Figure 6 shows the equipment.

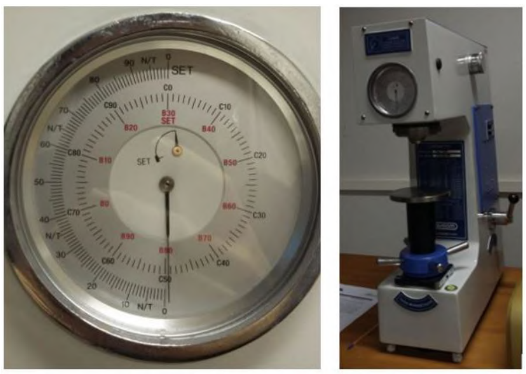

Figure 6. Hardness testing machine.

2.4 Tensile test

Tensile tests were performed using ASTM E8/E8M-13a (2013) as reference. Figure 7 shows the tensile test specimens.

Figure 7. Tensile test machine and the test specimens.

2.5 Metallography

The metallographic analysis was performed after achieving the best surface finish (2000 grit sandpaper and 1μm diamond paste for polishing) and a chemical attack of Nital 3%.

3. RESULTS AND DISCUSSIONS

3.1 Visual inspection of the specimens material

After cutting, a visual analysis was performed, before performing the machining of the specimens. In some sections it was verified internal shrinkage or spongy area lined with dendrites. Figure 8 shows a large shrinkage in the region of the bore of the drawbar rotating side. In addition to being in a critical area, this is a large defect. (AFS, 1994) and (ASM, 2008)

Figure 8. Section of the drawbar with a large internal shrinkage.

3.2 Fatigue Testing

The fatigue tests were performed on new and used parts, taken from the raw material cutted from the yoke and the drawbars. The aforementioned parts had reached their infinite service life. The seven samples taken from each part had the fatigue testing performed. For welded samples without heat treatment, two of seven ruptured, one specimen from drawbar with 2.89×10^5 cycles and other from yoke with 2.72×10^4 cycles.

Figure 9. Fragile rupture of the specimen taken from the drawbar without heat treatment.

Finally, for welded samples with heat treatment, two of seven were fractured, one from the drawbar with with 4.58×10^5 cycles and other from the yoke with 1.2×10^3 cycles. The specimens removed from the drawbar had no apparent defect, although they were removed from the site where the shrinkage was found. Whereas the specimens removed from the yoke showed pores that culminated in the rapid rupture of the material. Figure 10 shows the apparent pores in the specimen.

Figure 10. Test specimen taken from the yoke with pores (material welded and heat treated).

3.3 Hardness test

Table 1 shows the means for the hardness measurements, in Rockwell C (HRC) and in Brinell (BHN) (converted from ASTM E140-02 (2002)). It can be noted that the samples without heat treatment presented low hardness, with the mean value of 225 BHN being below the 241 BHN specified by the AAR (2005). These values were primarily expected, if taken into account the chemical composition of the wire used in the recovery process, which had carbon below 0.15%.

Table 1. Experimental results for hardness tests.

Sample	Hardness (HRC)	Hardness (BHN)
New (1)	25.5 ± 2.1	255
Used(1)	28.5 ± 4.2	275
Welded without heat treatment(1)	19.3 ± 3.3	225
Welded with heat treatment(1)	31.3 ± 4.7	297
AAR Specification M 201 Grade E	-	241 - 311

(1) measured at 25°C

3.4 Tensile test

Table 2 shows the results of the tensile tests. The material without heat treatment had low mechanical strength, while the treated material had good mechanical strength, but low elongation and reduction in area. This is an alert point and indicates that the current tempering temperature should be increased.

Table 2. Experimental results for tensile test.

Sample	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Reduction in Area (%)
New(1)	807	917	12	25
Used(1)	803	911	18	52
Welded without heat treatment(1)	560	692	18	51
Welded with heat treatment(1)	886	929	6	20
AAR Specification M 201 Grade E	689	827	14	30

(1) measured at 25°C

Figure 11. Specimens after the tensile test.

3.5 Metallography

The metallographic analysis was performed for all the cases shown. According to Colpaert (1974), the expected microstructure for this material was tempered martensite, which is presented in Fig. 12.

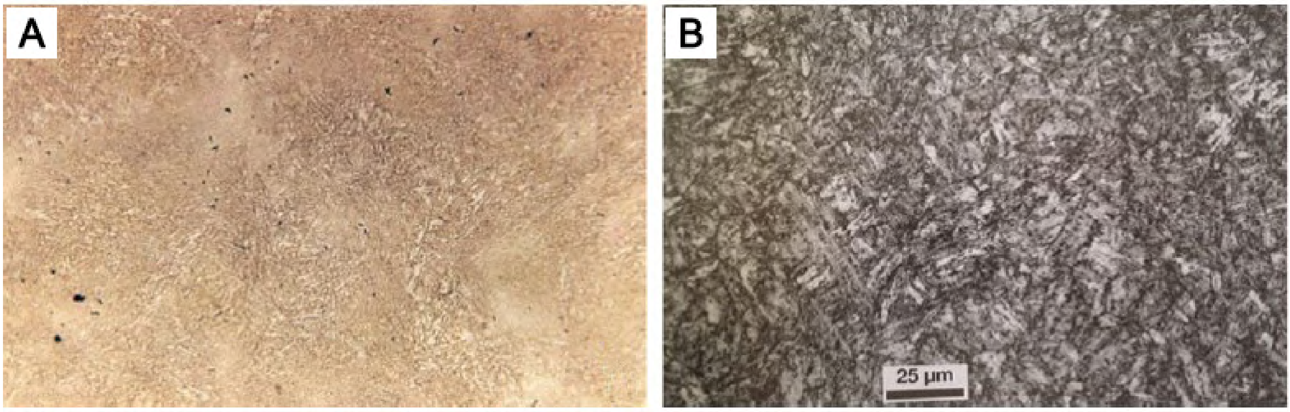

Figure 12. (A) Typical photomicrograph of quenched and tempered AAR M201Grade E steel (Alves and Sinatora, 1997); (B) Typical photomicrograph of low alloy steel quenched and tempered (Colpaert and Costa e Silva, 2008, p. 305).

Figures 13 and 14 show the photomicrograph of the sample for new material, used material and welded material after heat treatment, respectively.

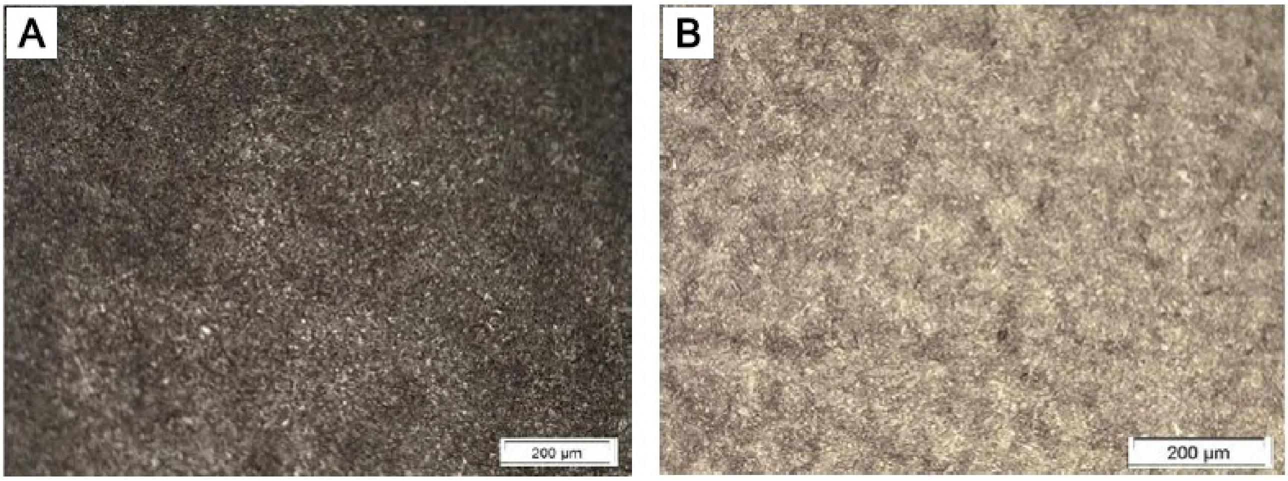

Figure 13. (A) Photomicrographs of the new material and (B) the worn one.

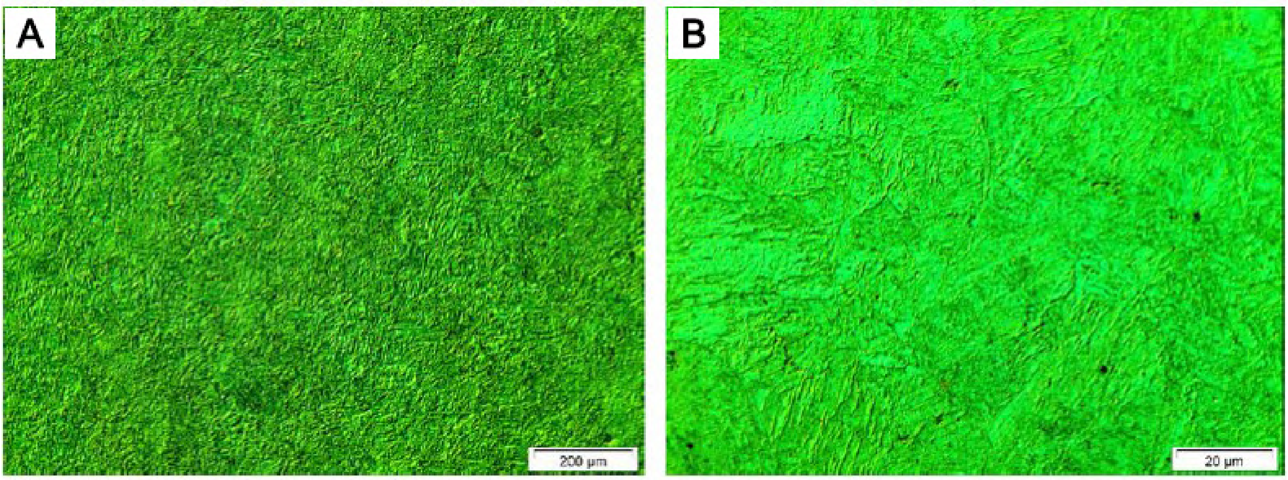

Figure 14. (A) and (B) Photomicrographs of recovered material with heat treatment.

However, the material recovered without heat treatment showed a different microstructure, known Widmanstätten ferrite, being very brittle and undesirable for a material subjected to great stress. Figure 15(A) exemplifies this microstructure according to the literature and (B) in the material without heat treatment.

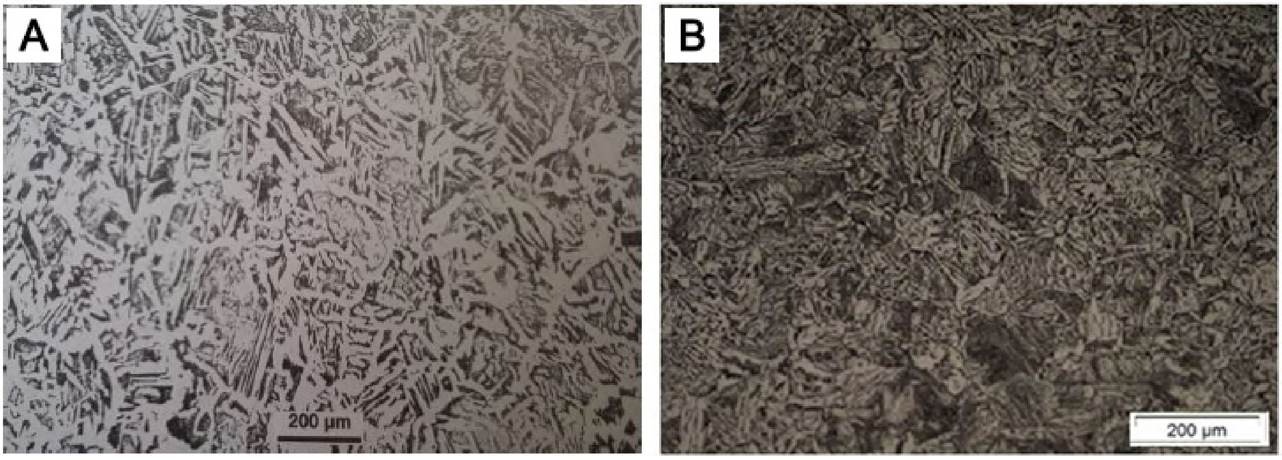

Figure 15. (A) "Widmanstatten" acicular ferrite (Colpaert and Costa e Silva, 2008, p. 232); (B) material recovered without heat treatment.

3.6 Tempering

The hardness values presented in the recovered and heat treated parts were very high. Whereas the values of ductility and reduction in area were very low (see Tab. 2). This suggests that the temperatures used for tempering were very low. According to the manufacturer's procedure, the tempering temperature was 500°C for one hour. To improve the ductility properties, a new tempering was performed at temperatures of 560 and 590°C, during one hour for each sample in a electric furnace. After tempering, the samples were cooled in water in order to avoid temper embrittlement.

3.6.1 Analysis of internal quality

No expressive points of internal faults were found in the samples collected, however the pieces are not free of micro defects, as it can be observed in an optical microscope analysis.

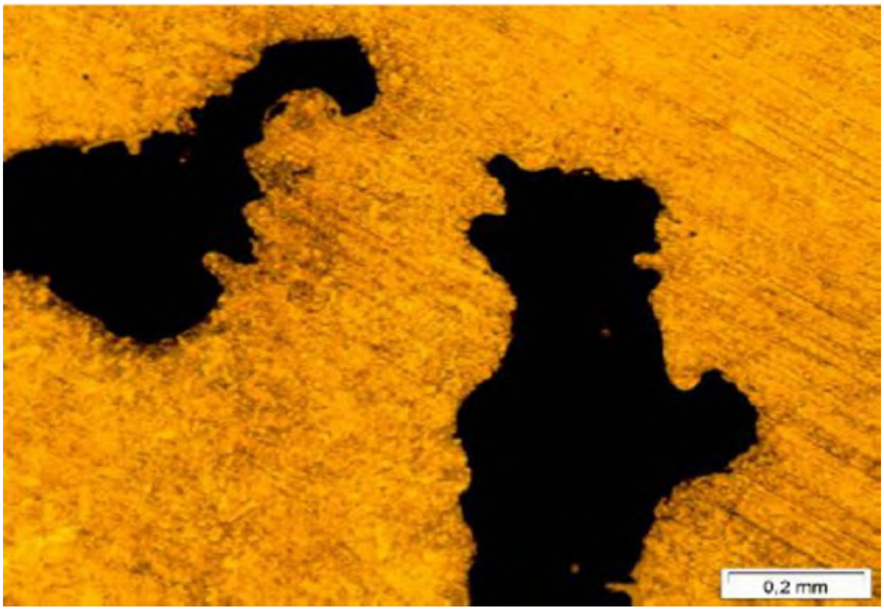

Figure 16. Micro defects obtained under optical microscope analysis.

3.6.2 Fatigue test

The fatigue testing was performed under the same conditions (273 MPa Maximum stress) for all samples. Then, eight new specimens were machined, four test specimens for each tempering temperature.

Two fractures occurred during the experiments: the first specimen from the drawbar at 560°C, due to a slight eccentricity, and the second one from the yoke at 590°C, which, after reaching infinite life, fractured after 1.9×10^6 cycles.

3.6.3 Hardness test

The results of the hardness test are shown in Tab. 3 below.

Table 3. Experimental results for hardness testing after tempering.

Sample	Hardness (HRC)	Hardness (BHN)
Tempered Material at 560°C	25.3 ± 2.1	250
Tempered Material at 590°C	22.0 ± 3.0	233
AAR Specification M 201 Grade E	-	241 - 311

$^{(1)}$ measured at 25°C

It can be observed that the sample with tempering temperature at 590°C obtained systematically low hardnesses, while the sample at 560°C is within the specifications suggested by the AAR (2005) - M201 E.

3.6.4 Tensile test

The results of the tensile test are shown in Tab. 4 below.

Table 4. Experimental results for tensile testing after tempering.

Sample	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Reduction in Area (%)
Drawbar tempered at 560°C	731	821	17	37
yoke tempered at 560°C	747	844	20	58
Drawbar tempered at 590°C	570	740	22	49
yoke tempered at 590°C	680	683	17	46
AAR Specification M 201 Grade E	689	827	14	30

$^{(1)}$ measured at 25°C

It can be observed that increasing the temper temperature results into significant elongation and reduction in area. On the other hand, mechanical properties such as the yield and tensile strength tempered at 590°C were rejected according to the standard AAR (2005) - M201 E. Therefore, the temperature of 560°C was more adequate.

3.6.5 Metallography

The microstructure obtained at the two temperatures employed in the tempering was the tempered martensite.

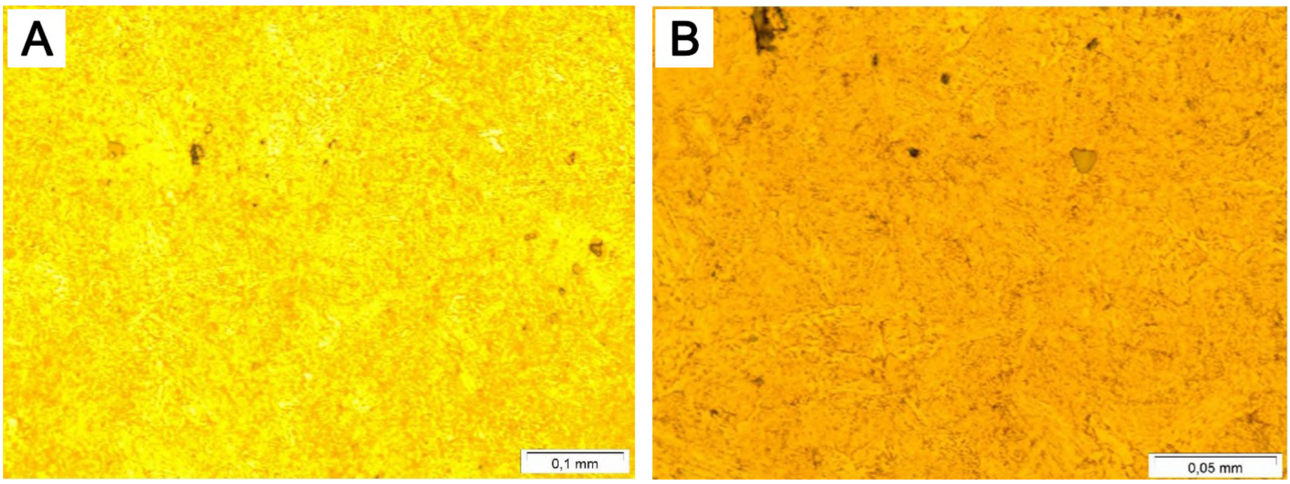

Figure 17. (A) and (B) Microstructure of the treated material at 560°C.

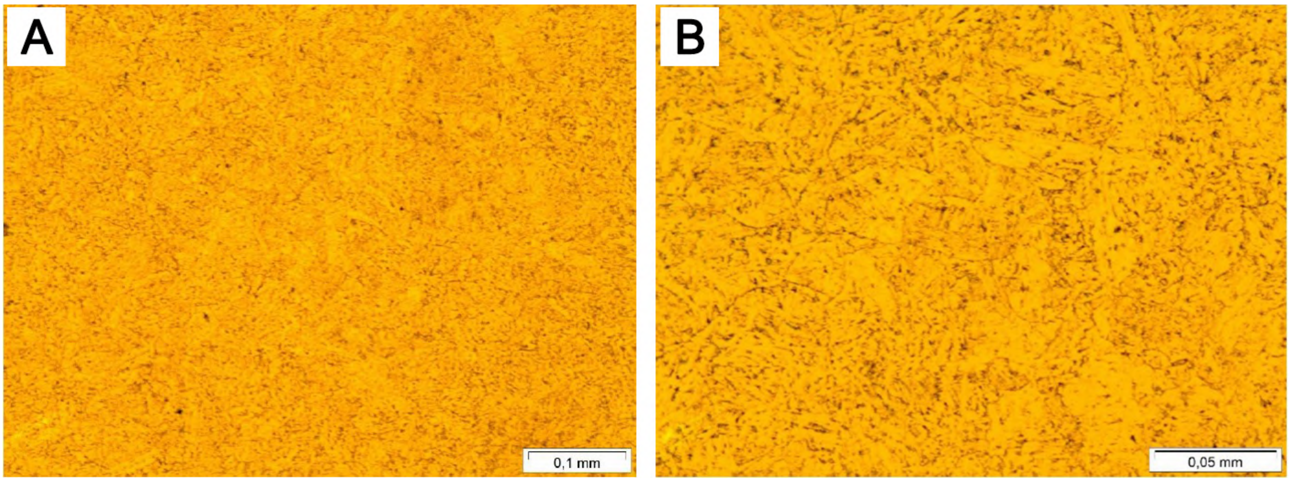

Figure 18. (A) and (B) Microstructure of the treated material at 590°C.

4. CONCLUSIONS

All the tests on new and used parts showed appropriate behavior. Therefore, it is possible to increase the time of use of these elements for more than 12 years in a safe way.

The materials recovered without heat treatment were rejected in the tensile and hardness tests, and had an inadequate microstructure that should have presented a worse fatigue behavior. But that did not happen. This is probably due to the position in which this fragile microconstituent was verified. But this presence of Widmanstätten ferrite is not recommended for this type of material.

The parts recovered with heat treatment had failures in the fatigue tests, but they are due to the fact that the samples were taken from a region of the drawbar that presented a great shrinkage and porosity. As for the hardness values, they were very high, while the ductility and the reduction in area measured in tensile tests were low. This suggests that the temperatures employed in the tempering were very low.

After tempering was done at 560 and 590°C, new tests were carried out. For 560°C, all mechanical properties met the specifications, while for 590°C, the strength as well as the hardness were below specifications. In the fatigue tests, the specimens tempered at 560°C also performed well, exceeding 1 million cycles. The micrographic analyses in both cases revealed a suitable microstructure, i.e., tempered martensite. Therefore, the 560°C temperature is more suitable for the tempering process of this material since it meets the mechanical properties specifications and presents good performance in fatigue.

In general, the results presented in this work were very positive and led to a significant increase in the life of the components of the shock and traction system, especially after recovery and adequate heat treatment.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

AAR, 2005. *Manual of Standards and Recommended Practices – Castings Steel - Specification M-201-E*. The Association of American Railroads, Washington D.C., United States of America, 18th edition.

AFS, 1994. *Analysis of Casting Defects*. American Foudrymen's Society Publishing, Des Plaines, United States of America, 3rd edition.

Alves, L.H.D., Borges, M., Sisdelli, A., Ferreira, J. and Castro, E., 2015. "Improving the draft system components performance for iron ore transportation". In *The 10th International Heavy Haul Association Conference-2015*. Perth, Australia.

Alves, L.H.D. and Sinatora, A., 1997. "Aços fundidos resistentes ao desgaste empregados em componentes ferroviários". In *XXVIII Seminário sobre fusão, refino e solidificação dos aços*. Campinas, Brazil.

ASM, 2008. *Metals Handbook - Casting*, Vol. 15. ASM International, Materials Park, United States of America, 9th edition.

ASTM A370-14, 2014. "Standard test methods and definitions for mechanical testing of steel products". Technical report, ASTM International.

ASTM E140-02, 2002. "Standard hardness conversion tables for metals relationship among brinell hardness, vickers hardness, rockwell hardness, superficial hardness, knoop hardness and scleroscope hardness". Technical report, ASTM

International.

ASTM E18-15, 2015. "Standard test methods for rockwell hardness of metallic materials". Technical report, ASTM International.

ASTM E8/E8M-13a, 2013. "Standard test methods for tension testing of metallic materials". Technical report, ASTM International.

Budynas, R.G. and Nisbett, J.K., 2011. *Elementos de máquinas de Shigley: Projeto de Engenharia Mecânica*. AMGH, Porto Alegre, Brazil, 8th edition.

Colpaert, H., 1974. *Metalografia dos Produtos Siderúrgicos Comuns*. Edgard Blucher, São Paulo, Brazil, 3rd edition.

Colpaert, H. and Costa e Silva, A., 2008. *Metalografia dos Produtos Siderúrgicos Comuns*. Edgard Blucher, São Paulo, Brazil, 4th edition.

Juvinall, R.C. and Marshek, K.M., 2008. *Fundamentos do projeto de componentes de máquinas.* LTC, Rio de Janeiro, Brazil, 4th edition.

Reed-Hill, R.E., 1982. *Princípios de Metalurgia Física*. Guanabara dois S.A., Rio de Janeiro, Brazil, 2nd edition.

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