WEAR BEHAVIOUR OF AISI 1024, AISI P20 AND AISI 304 HOT ROLLED STEELS USED IN ORGANIC WASTE TREATMENT INDUSTRY

COMPORTAMENTO AO DESGASTE DOS AÇOS LAMINADOS A QUENTE AISI 1024, AISI P20 E AISI 304 PARA APLICAÇÃO NA INDUSTRIA DE TRATAMENTO DE LIXOS ORGÂNICOS

Ricardo Paulo[1], Teresa Morgado[1, 2, 3]

[1]DEMI – Mechanical and Industrial Engineering Department, FCT NOVA - Faculty of Science and Technology, Universidade Nova de Lisboa, Lisboa, Portugal, email: r.paulo@campus.fct.unl.pt; t.morgado@fct.unl.pt;
[2]UNIDEMI – Research and Development Unit for Mechanical and Industrial Engineering, FCT NOVA - Faculty of Science and Technology, Universidade Nova de Lisboa, Lisboa, Portugal
[3]IPT- Polytechnic Institute of Tomar, Portugal tmorgado@ipt.pt;


ABSTRACT

This paper was based on a real case of a screw used to move the waste, which presented integrity problems. A screw from the solid waste treatment industry which had the function of moving the organic waste, therefore subjected to a corrosive environment, was studied. The interaction of the mechanical component with the waste tends to speed up the wear process, resulting in a low equipment life/durability. This study compares the wear behaviour of three rolled steels for the production of a screw. AISI 1024, AISI P20 and AISI 304 steels were tested on a pin-on-disk apparatus, under the influence of three different wastes which acted as corrosive environments during the pin-on-disk wear test. Two wastes were organic with different compositions, and another one organic with addition of glass particles.

Keywords: hot rolled steel, AISI 1024, AISI P20, AISI 304 hardness, wear, screw, ecodesign.

RESUMO

Este artigo estuda o comportamento ao desgaste e dureza de três ligas de aço laminado a quente, AISI 1024, AISI P20 and AISI 304, possíveis soluções para construção de um parafuso sem fim, que tem como função mover lixo orgânico num equipamento de tratamento de resíduos sólidos. Este tipo de componentes mecânicos está sujeito a resíduos sólidos de diferentes naturezas /ambientes, nomeadamente ambientes ácidos e com partículas sólidas extremamente abrasivas que resulta numa durabilidade extremamente baixa, ou seja apresentam problemas de integridade estrutural graves. Este trabalho apresenta o estudo da influência de três tipos de lixos diferentes, dois orgânicos com diferentes composições e outro orgânico com adição de partículas de vidro através de ensaios de desgaste do tipo pin-on-disk, na integridade estrutural dos diferentes aços.

1. INTRODUCTION

This study is based on a screw used to move the waste on an organic waste treatment industry. The screw is mainly composed by two parts, the main body and the flights. The main body presented a variable diameter identical to screws used in screw presses and flights are made from a steel plate which is then bent to obtain a specified pitch and then welded to the main body. Knowing the chemical composition of the screw, a similar steel was selected. AISI 1024 (ST52), a structural carbon steel, was considered, in this study, as the basis of comparison to other steels.

From the interaction between the solid waste and the rotating screw occurs damage caused by corrosion and wear of the component. This wear is mainly identified as adhesive, abrasive and corrosive wear. The environment where the tests are performed is of great influence to the wear rate. Small particles formed by corrosion can influence the wear, as these particles work as an abrasive agent (Lyu, Zhu, & Olofsson, 2015). Usually, under atmospheric conditions, the wear rate is lower than those under the influence of corrosive environment (Li et al., 2016). Different materials revealed different wear rates. Whereas iron-cast electrode revealed higher wear resistance for low operating speeds, stainless steel electrode performed best at high speeds (Aluko, Oluwadare, Ola, & Makanjuola, 2003).

One of the objectives of this study was to present a possible solution to extend the component durability, so, two more materials were selected. The wear behaviour of those two materials was also studied so it was possible to compare with the equivalent to the original one.

2. EXPERIMENTAL PROCEDIMENT

2.1 Material Selection

It is a known fact that the presence of certain elements on the steel composition improves their corrosion and wear resistance. Therefore, AISI P20 steel (2738) was selected as it is a structural alloy steel, expected to present higher hardness than a structural carbon steel. An important characteristic of the material for this study was corrosion resistance, thus a stainless steel was selected, AISI 304 stainless steel (R304). Table 1 presents the three materials object of this study and their corresponding chemical composition.

2.2. Microindentation Hardness of Materials

To evaluate the hardness of materials, the Vickers microindentation hardness tests were conducted following the ASTM standard E384-16: Standard Test Method for Microindentation Hardness of Materials (ASTM Standard E384-16, 2016).

The preparation of specimens for the hardness test was performed according to the ASTM standard E3-95: Standard Practice for Preparation of Metallographic Specimens (ASTM Standard E3-95, 1995). A single stripe was cut from the original steel plate, which was then dived into three sections entitled A, B and C. Each of those sections were then cut into three samples entitled T, F and P which stand for the orientation, Top, Front and Profile view (figure 1 (a)). In figure 1 (b) is shown the specimen sectioning representation on a SolidWorks model. In order to prevent the cutting process from influencing the steel microstructure and therefore the hardness results, a semi-automatic lubricated saw was used to cut the specimens.

Table 1 – Steels and their chemical composition.

Steels	**Elements [%]**										
	C	**Si**	**Mn**	**P**	**S**	**Cr**	**Ni**	**Mo**	**Al**	**N**	**Cu**
Original	0,17	0,31	1,40	0,014	0,014	0,08	0,04		0,06		0,07
ST52	0,22	0,55	1,60	0,030	0,030					0,012	0,55
2738	0,45	0,40	1,60	0,030	0,010	2,10	1,20	0,25			
R304	0,07	1,00	2,00	0,045	0,030	18,50	13,00				

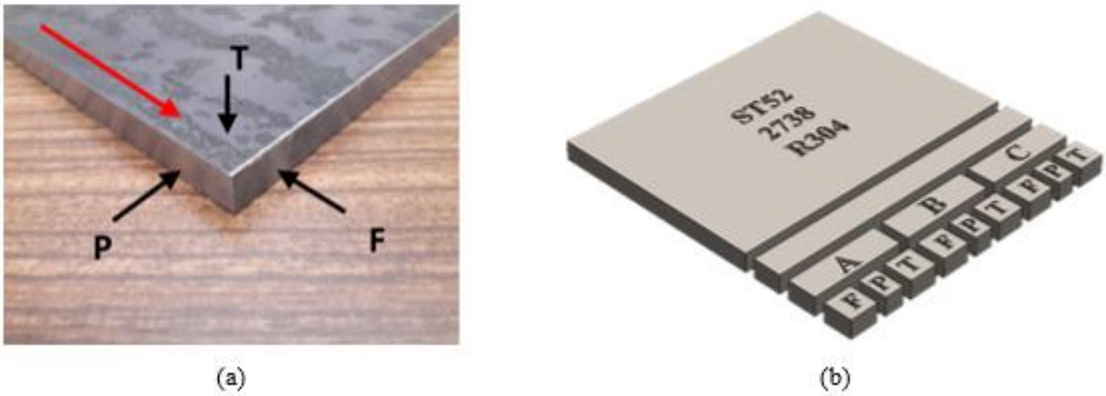

Fig 1 - Identification and representation of: (a) different views and rolling direction and (b) test specimens.

Epoxy resin was used to provide a better support to specimens due to their dimensions. Towards the surface preparation of the specimens, a manual grinding machine was used following a specified sandpaper sequence: 80, 240, 320, 400, 600, 1200 e 2500. Lastly the specimens were subjected to polishing with a specific cloth and 1 µm diamond paste.

The process of preparation of specimens was conducted equally for the three steels in this study, resulting in a total of 27 specimens for hardness testing. For these tests a load of 500 gf was applied for 10 seconds, the distance between indentations (10 by specimen) was 300 µm.

Once the results were obtained, a statistic software was used to confirm that the results followed a normal distribution as requested by the ASTM 384-16 standard. Anderson-Darling test was used.

2.3 Wear Tests

A pin-on-disk tribometer was used to assess the wear behavior of the three steels. The tests were conducted according to the ASTM standard G99-95a: Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus (ASTM Standard G99-95a (2000)).

Tribometers are commonly used to evaluate the wear behavior of materials based on volume loss and friction, however, in this study a thermocouple was added to determine the temperature of the pin near the contact area. In figure 2 the pin-on-disk apparatus is presented, however, in order to perform wear tests under the influence of corrosive environments, a specimen holder adapter was designed and 3D printed.

For the wear test, 9 specimens per material were prepared following three steps. Firstly, the steel plates were cut with a semi-automatic lubricated saw into specimens with 30 mm in length and 30 mm wide (figure 3 (a)). Secondly, in order to meet the ASTM G99-95a standard requirements, the specimens were grinded in a grinding machine which is capable of conferring a surface roughness less than 0.8 µm. Lastly, to confirm the requirement, the specimen's surface roughness was evaluated in three different directions as identified in figure 3(b) with a mobile roughness measuring instrument Mahr MarSurf PS10.

The pin used for the wear test was grinded with sandpaper in the drilling device to achieve a round tip. This process was repeated before every test. In addition to the round tip, a cut was made 5 mm from the tip, to secure the thermocouple.

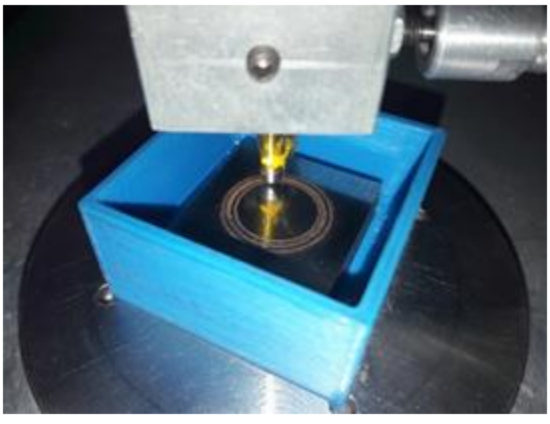

Fig 2 - Equipment used for wear test: (a) Pin-on-Disk apparatus and (b) detail of the wear track.

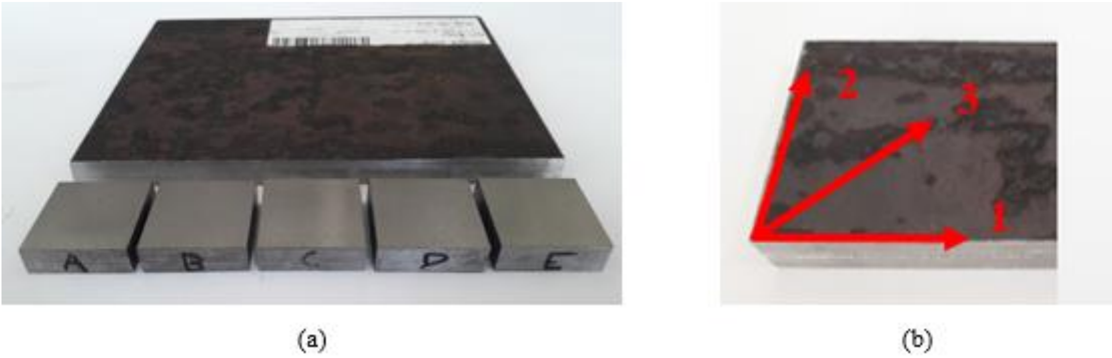

Fig 3 - Specimens: (a) cut and identification and (b) roughness evaluation directions (Paulo, 2017).

Relatively to the corrosive environment, three different wastes were prepared. The first waste was prepared using lemon, which was crushed to a paste-like consistency. The second waste was prepared in the same way as above and then added glass particles crushed from a glass. The last waste was prepared with lemon adding eggshell and potato peel.

The parameters used for the wear tests were a linear speed of 0.1 m/s, which corresponded to a rotational speed of the motor of 835 rpm, and loads of 16.93N, 30.84N e 41.14N. The load of 41.14N was the most effective without compromising the test, therefore, used in the 27 tests. These tests were performed for 30 minutes, having started at room temperature (≈25º C). However, the contact temperature between the disk and the pin tends to rise as the friction increases.

3. RESULTS

The hardness tests revealed consistency within the values obtained along the specimens. The Vickers hardness value for ST52 steel was 157±1HV, 320±2HV for 2738 steel and for R304 was 159±2HV.

According to the ASTM G99-95a, the results from the wear tests are shown in volume loss. Therefore, in table 2 the result of each wear test, three specimens per waste for each steel, was presented.

Table 2 - Wear tests results measured by volume loss

Volume Loss of Material			
Steel	**Waste 1 [mm^3]**	**Waste 2 [mm^3]**	**Waste 3 [mm^3]**
ST52	0.1538	0.2436	0.0897
	0.3077	0.5641	0.1282
	0.1538	0.5897	0.0769
2738	0.3462	0.5641	0.0128
	0.5385	0.5128	0.0897
	0.3590	0.7436	0.1282
R304	0.1154	1.5000	0.2179
	0.1795	1.3590	0.1410
	0.1026	0.5897	0.4100

Figure 4 shows surface photography's of the pin and sample H of ST52, at the end of the test, made with steel in waste 2, where was verified the existence of two stages (see figure 4a) and 4b). The stage one, with friction force between 10N and 15N, friction coefficient between 0.2 and 0.4 and the maximum test temperature of 32ºC. In second stage, the maximum value of friction force was 23 N, stabilized 100 seconds after to a value of 17 N, and the maximum temperature was 42ºC. The difference between the two stages may be due to the presence of the glass particles, since the greater the width of the wear track the greater the probability of particle accumulation promoting the increase of the frictional force.

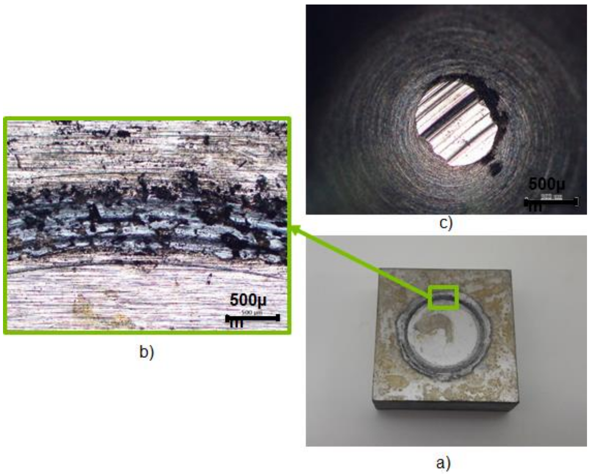

Fig 4 - ST52-H Waste 2 wear test results: (a) Sample after test; (b) wear track detail and (c) test pin tip detail after the test (Paulo, 2017).

In figure 5 are shown the average of results per waste for each steel. The pin used for the wear tests was also weighted before and after the tests so that the volume loss could be calculated, however, the mass difference was only about 0.0002g, thus this parameter was not taken into consideration.

For waste 1, even though R304 steel presented a friction coefficient of 0.25 which is higher than the friction coefficient for ST52 and 2738 steels (about 0.15), was the one with less volume loss.

The two structural steels, ST52 and 2738, were found to present almost the same volume loss under the influence of waste 3. In fact, those were the lowest volume loss results identified within all tests.

As expected, all materials tested with organic compositions (waste 1 and 3) presented more uniform friction coefficient results than those with waste 2 (addition of glass particles). In those testes with waste 2, several peaks were found which may be due to the uncertainty of the presence of glass particles in the contact area between the pin and the specimens.

Figure 6 shows the friction coefficient results of wear tests under the influence of waste 2 for steel ST52, 2738 and R304.

For all three materials, the tests with waste 2 presented higher volume loss showing the influence of non-organic materials on wear rates. For ST52 steel, two stages of friction coefficient were found, 0.24 for the first stage and 0.29 on the second one. For 2738 steel the average of friction coefficient was about 0.16. The most significant variations were found with the R304 steel wear tests with waste 2, the average friction coefficient was 0.3. However, during the tests were found some peaks reaching a coefficient of friction of 0.35 and 0.61, resulting in a higher volume loss, which shows the influence of glass particles on R304 steel wear.

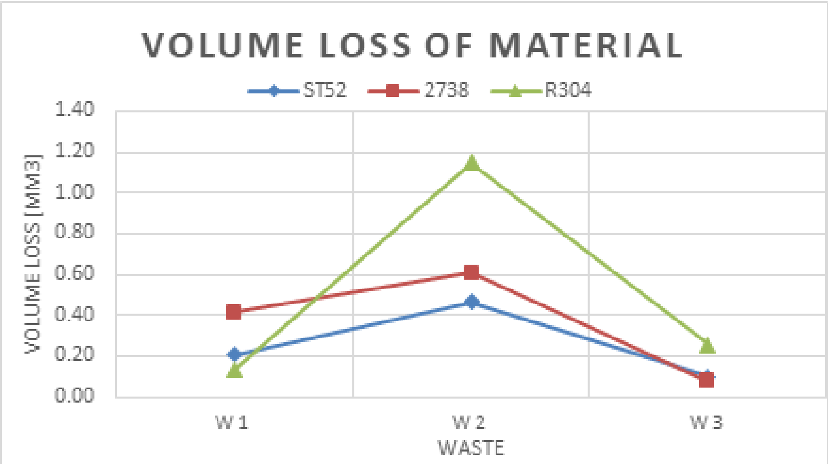

Fig 5 - Volume loss of materials per waste.

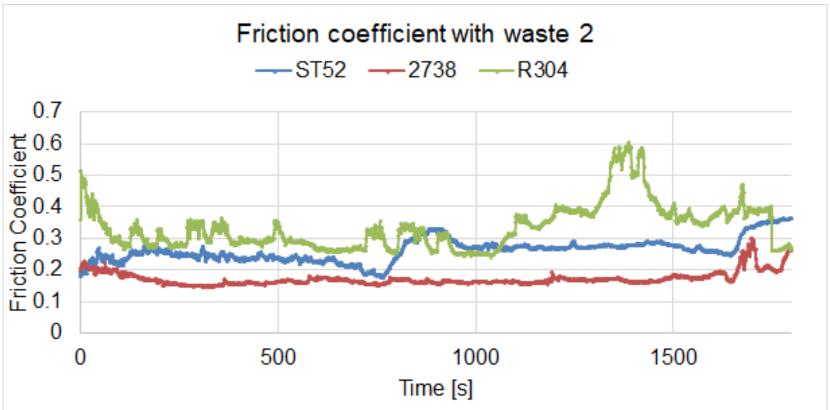

Fig 6 - Friction coefficient of steels during wear test with waste 2.

4. CONCLUSIONS

With this study it is possible to conclude that all steels suffered a greater volume loss under the influence of waste 2, because the glass particles act as an abrasive material, resulting in a fast material removal. Therefore, only under ideal conditions, that is, an entirely organic waste, the R304 stainless steel would be a possible solution. Referring to hardness, although the steel 2738 had twice the hardness of the ST52 steel, no significant increase in wear resistance was noticed. In fact, 2738 steel presented a volume loss higher than ST52 steel.

ACKNOWLEDGMENTS

The authors from FCT NOVA would like to acknowledge Fundação para a Ciência e a Tecnologia (FCT, I.P.) for financial support via PEst-OE/EME/UI0667/2014.

REFERENCES

Aluko, O. B., Oluwadare, G. O., Ola, I. A., & Makanjuola, G. A. (2003). Rapid comparative wear evaluation of oilseed screw press maintenance materials in Nigeria. *Journal of Food Engineering*, *59*(2–3), 111–116. https://doi.org/10.1016/S0260-8774(02)00437-5

ASTM Standard E3-95. (1995). *Standard Practice for Preparation of Metallographic Specimens*. *ASTM International*. West Conshohocken, PA. https://doi.org/10.1520/D0638-14.1

ASTM Standard E384-16. (2016). *Standard Test Method for Microindentation Hardness of Materials*. *ASTM International*. West Conshohocken, PA. https://doi.org/10.1520/E0384-16

ASTM Standard G99-95a (2000). *Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus*. *Annual Book of ASTM Standards G-99-95a*. West Conshohocken, PA. https://doi.org/10.1520/G0099-05R10.2

Li, X., Zhou, Y., Cao, H., Li, Y., Wang, L., & Wang, S. (2016). Wear Behavior and Mechanism of H13 Steel in Different Environmental Media. *Journal of Materials Engineering and Performance*, *25*(10), 4134–4144. https://doi.org/10.1007/s11665-016-2223-0

Lyu, Y., Zhu, Y., & Olofsson, U. (2015). Wear between wheel and rail: A pin-on-disc study of environmental conditions and iron oxides. *Wear*, *328–329*, 277–285. https://doi.org/10.1016/j.wear.2015.02.057

Paulo, R. (2017). *Evaluation and charaterization of wear behaviour of rolled steels for the production of a screw*. Master Thesis (in Portuguese), FCT-NOVA.