SCRATCH TESTING OF ALUMINUM AA1060

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Abstract

The scratch testing is carried out according to the ASTM G171-03 standard and the scratch hardness numbers of three aluminum AA1060 specimens to three different scratching speeds (53, 76 and 98 mm s^{-1}) is determined. The results are compared with those obtained by the scratch testing simulation and similar results are observed. Nevertheless, the model used to simulate the scratch testing with the purpose of obtain more accurate results according to the test should be improved. Also, as a result of the simulation the stresses and strains behavior are obtained during the scratch process.

Keywords: Scratching; Aluminum AA1060; Scratch Hardness Number; Finite Element Method

1 Introduction

Currently, the industry has increased the interest in making tribological systems more efficient, for which the study of the mechanical behavior of materials of machine elements is necessary [2]. Moreover, the analysis of stresses and strains under sliding contact play an important role, because through experimental studies and simulations one can analyze mechanical properties of substrates and surface protection for various industrial applications.

Wear is found in most of the production processes and can occur through various mechanisms, such as adhesion, abrasion, erosion, fatigue and impact [3]. One of the main mechanisms is abrasive wear, which occurs frequently and appears when high hardness particles make contact with the ductile surface of machine elements, resulting in deformation and subsequent cutting and lifting the surface material. Scratching is a special case of abrasive wear.

Finite Element Method (FEM), has been used to study certain mechanical properties of materials surface and coatings [4,6], for which are simulated indentation and scratching processes. Also, it permits knowing the mechanical behavior of the stresses and strains of the material [5].

Therefore, costly experiments are needed to obtain some properties of tribological pairs, which are indispensable for your design. Although in recent times has been used FEM to simulate some phenomena of contact, some problems that have not been addressed and that are of great importance for knowing the properties of a particular tribological pair.

2 Scratch Testing

Scratch testing, according to ASTM G171-03 standard [9], consist on producing a scratch in a solid surface by moving a diamond stylus of specified geometry along a specified path under a constant normal force and with a constant speed. The average width of the scratch is measured, and that value is used to compute the scratch hardness number in units of pressure.

2.1 Material Properties

The chemical composition of the specimen material was ignored but it was carried out five shots (fig. 1) to a sample with a Belec Spektrometrie Opto-Elektronik throwing the results showing in table 1.

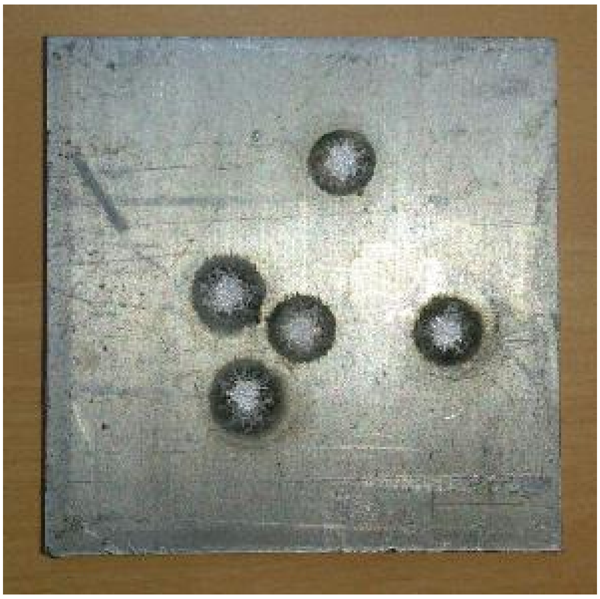

Figure 1: Specimen Shots

No.	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Sn	Ti	Pb	V	Co	Al
1	0.088	0.278	<0.001	<0.001	0.008	<0.001	<0.001	<0.001	<0.001	0.027	<0.001	0.005	<0.001	99.59
2	0.077	0.253	<0.001	<0.001	0.004	<0.001	<0.001	<0.001	<0.001	0.027	<0.001	0.005	<0.001	99.63
3	0.086	0.261	<0.001	<0.001	0.006	<0.001	<0.001	0.002	<0.001	0.027	<0.001	0.005	<0.001	99.60
4	0.081	0.252	<0.001	<0.001	0.004	<0.001	<0.001	<0.001	<0.001	0.025	<0.001	0.004	<0.001	99.63
5	0.079	0.285	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	0.028	<0.001	0.005	<0.001	99.59
	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Sn	Ti	Pb	V	Co	Al
Ave.	0.082	0.266	<0.001	<0.001	0.005	<0.001	<0.001	<0.001	<0.001	0.027	<0.001	0.005	<0.001	99.61

Table 1: Chemical Composition of Specimen

According to the chemical composition the specimens are made of aluminum AA1060 [7], because their alloy composition is among the following ranges [10]:

- Aluminum (Al): 99.6 to 100%
- Iron (Fe): 0 to 0.35%
- Silicon (Si): 0 to 0.25%
- Cooper (Cu): 0 to 0.05%
- Vanadium (V): 0 to 0.05%
- Zinc (Zn): 0 to 0.05%
- Magnesium (Mg): 0 to 0.03%
- Manganese (Mn): 0 to 0.03%
- Titanium (Ti): 0 to 0.03%

2.2 Procedure

It was carried out the scratch testing to three aluminum specimens (50x50x5 mm) previously prepared (0.8 µm Ra) and cleaned with Toluene (non-polar solvent).

In the test a diamond stylus type Rockwell C has been used. The normal force applied was of 30 N in all the cases and was measured with a Kraftmessgerate Halle Dynamometer (fig. 2).

Figure 2: Kraftmessgerate Halle Dynamometer

The three specimens were subjected to three different scratching speeds. These speeds were calculated starting from the drive speed that was measured with a Laser Digital Tachometer (fig. 3).

Figure 3: SHIMPO DT-205L Laser Digital Tachometer

Three scratch (approximately 3 cm each one) were carried out in each specimen (fig. 4). The first specimen was scratched with a scratching speed of 53 mm s^{-1}, the second at 76 mm s^{-1} and the third at 98 mm s^{-1}.

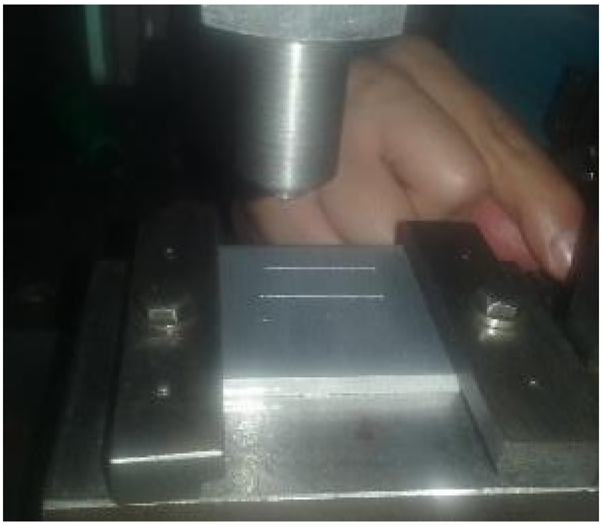

Figure 4: Scratch Testing Apparatus

The scratch width was measured with a Monocular (fig. 5). Three measurements were realized for each scratch, that is, nine measurements for specimens. The results are shown in table 2.

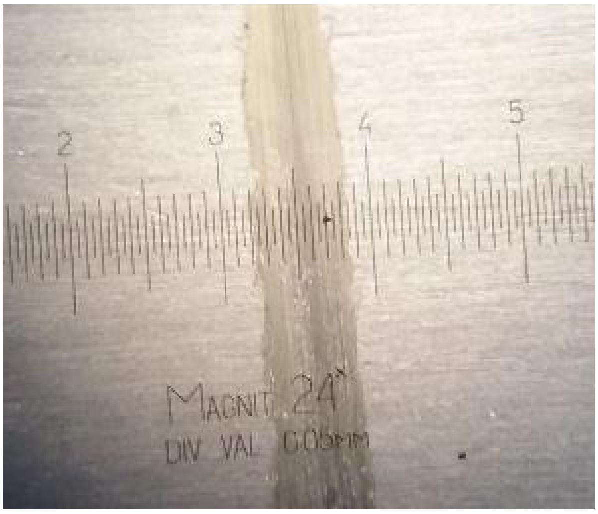

Figure 5: Scratch Width

Measurements of Scratch Width (mm)			
Number	Specim. 1	Specim. 2	Specim. 3
1	0.55	0.55	0.55
2	0.65	0.60	0.55
3	0.65	0.65	0.60
4	0.65	0.65	0.55
5	0.60	0.70	0.65
6	0.65	0.75	0.60
7	0.55	0.60	0.60
8	0.60	0.55	0.65
9	0.60	0.55	0.70
Average	0.61	0.62	0.61

Table 2: Scratch Widths Measurements

2.3 Scratch Hardness Numbers

The average scratch widths were converted to average scratch hardness number using the next equation [1,8,9].

$$HS_P = \frac{8P}{\pi w^2} \qquad \text{(Eq. 1)}$$

where:

HS_P = scratch hardness number, Pa,
P = normal force, N, and
w = scratch width, m.

The scratch hardness numbers of each specimen are shown in table 3.

Scratch Harness Numbers GPa			
	Specim. 1	Specim. 2	Specim. 3
Average	0.205	0.199	0.205

Table 3: Scratch Hardness Numbers

3 Simulation of Scratch Testing

The simulation of scratching was realized in a 2D model. This consists on a first step where the indenter penetrates to the substrate and a second step when the indenter scratching the surface.

3.1 Indenter

The indenter is an analytical rigid part that consist in a conical of apex angle 120° and the cone terminate in a hemispherical tip of 200 µm radius. The dimensions of indenter are shown in the next sketch (fig 6).

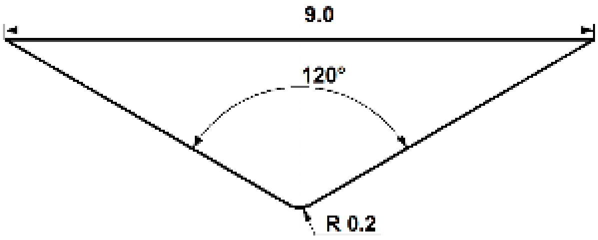

Figure 6: Indenter Sketch

3.2 Substrate

The substrate is a deformable part with the dimensions according to the next sketch (fig. 7).

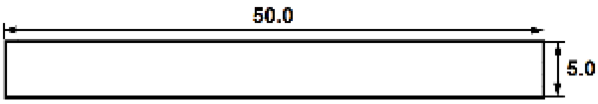

Figure 7: Substrate Sketch

3.3 Scratching

The indenter was assembled to the substrate in such a way that is positioned at 10 mm of the top-left corner of the substrate.

During the whole analysis the substrate remains fixed in left, right and bottom sides. In the first step the indenter falls with a normal force of 30 N while their horizontal axis displacement and its rotation in the plane are restricted. In the second step the indenter moves 30 mm toward the right to a constant speed of 5 mm/s.

3.4 Simulation Results

As a result of the simulation it is observed the behavior of the stresses and strains in the substrate (fig. 8). Note like exist remainder stresses in the whole scratching zone and that the biggest stress is always in the contact area in the right corner of indenter, that is, in the direction of the movement.

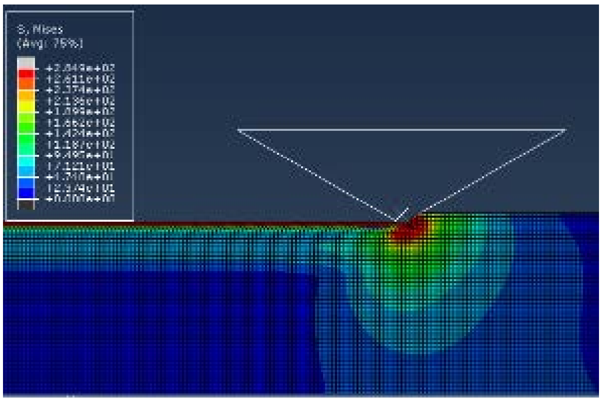

Figure 8: Von Mises Stress

3.5 Scratch Hardness Number

Keeping in mind the geometry of indenter and according to the penetrated depth (pd) you can calculate the scratch width (w) using the equation:

$$w = 0.2 + 2[pd - 0.2(1 - \sin 60°)] \tan 60° \quad \text{(Eq. 2)}$$

Then applying the equation 1 you can calculate the scratch hardness number.

pd in mm	w in mm	$HS_{30\,N}$ in GPa
0.17	0.69	0.160

Table 4: Scratch Hardness Number according to Simulation Results

4 Conclusions

An error exists between the average width of the testing (0.62 mm) and the simulation (0.69 mm) of 11%, and between scratch hardness number of the testing (0.205 GPa) and the simulation (0.160 GPa) of 22%, due to the inaccuracy of the simulation model that can be resolved improving the model. However, the results are quite similar demonstrating that acceptable predictions of scratch hardness numbers can be obtained by means of the simulation.

The scratching speed doesn’t affect the scratch width and therefore it doesn’t affect the scratch hardness number. Nevertheless, with the increase of the scratching speed also increase the difficulty in precisely locating scratch edges because they were deformed more.

It should be carried out the 3D model of the scratch testing for compares the resulting scratch hardness numbers with 2D model. If the obtained results are similar it will be able to decrease the time of calculation and the computational resources demanded due to the simplification of the problem.

5 References

[1] ADLER, Thomas A. & WALTERS, Richard P. Wear and scratch hardness of 304 stainless steel investigated with single scratch test. *Wear.* 1993. No. 162-164. 713-720 p.

[2] ASHBY, Michael F. & JONES, David R.H. Engineering Materials 2: An Introduction to Microstructures, Processing and Design. 3rd. ed. Oxford: Butterworth-Heinemann. 2006. ISBN: 0-7506-6381-2.

[3] ASM HANDBOOK COMMITTEE. ASM Handbook Vol. 8: Mechanical Testing and Evaluation. United State: ASM International. 2000. 2235 p. ISBN: 0-87170-389-0.

[4] DINESH KUMAR, D. [et al]. Substrate effect on wear resistant transition metal nitride hard coatings: Microstructure and tribo-mechanical properties. Ceramics International. 2015. No. 41. ISSN: 0272-8842.

[5] NEGRIN HERNANDEZ, Ivan. & PEREZ RUIZ, Eduardo A. Simulation analyses of the stresses and plastic strain during two body contact and sliding. *Scientia et Technica.* Year XIV, 2008. No. 39. 147-152 p. ISSN: 0122-1701.

[6] PEREZ RUIZ, Eduardo A., NEGRIN HERNANDEZ, Luis I. & MARTINS DE SOUZA, Roberto. Mechanical Behavior study of a coated system by computer simulation of the scratch test. *Ingeniería Mecánica*. Vol. 18. No. 2. 2015. 80-86 p. ISSN: 1815-5944.

[7] ROSENBERGER, M.R., FORLERER, E. & SCHVEZOV, C.E. Wear behavior of AA1060 reinforced with alumina under different loads. *Wear.* 2009. No. 266. 356-359 p.

[8] SINHA, S.K., REDDY, S.U. & GUPTA, M. Scratch hardness and mechanical property correlation for Mg/SiC and Mg/SiC/Ti metal-matrix composites. *Tribology International*. 2006. No. 39.

[9] Standard Test Method for Scratch Hardness of Materials Using a Diamond Stylus. ASTM Standard designation: G171-03.

[10] WANG Zongshen [et al]. Experimental investigation of pure aluminum sheets processed by constrained groove pressing. *Indian Journal of Engineering & Materials Sciences.* 2014. Vol. 21. 121-127 p.