Experimental Study of the Cutting Processes

Effect on the Surface Hardness of ASTM A36 Steel

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Abstract

This article analyses the hardness of ASTM-A36 steel both in its delivery state and after various cutting processes. The material was cut with different methods conventionally used in the metal-mechanic and construction industry, in addition to other non-conventional processes used to a lesser extent in the industry. In addition, similar cuts were made to maintain test homogeneity and to analyze the faces of the cut on each specimen in a similar manner. Among the conventional cuts made to the specimens are the milling machine, oxy-cutting and cutting machine, while the non-conventional ones were applied by EDM and plasma, maintaining as far as possible similar cutting and working parameters. Subsequently, the hardness of the cut surface of each of the specimens was studied using an AFFRI 250 DMRC durometer, which allowed quantifying the changes in the material depending on the cutting method used and defining according to each method that may affect the final application of the material. The

graphical results allowed a comparative analysis of all the methods used, as well as the differences found between them and to obtain important conclusions that can be used in the new techniques of the manufacturing processes.

Keywords: Hardness, Tests, Indenter, Cutting Processes

1. Introduction

The characterization of the effect of various cutting methods on the surface properties of ASTM A-36 steel, particularly on hardness, has been studied since it is one of the basic mechanical properties of materials that defines the ability to resist scratches, cuts, abrasion and another surface damage. It has also been considered as the main factor affecting the wear resistance of cutting tools [1].

Knowing the level of hardness of a material is important for its correct use in any process, in different industrial fields such as architecture, metallurgy, and automotive production, since tests must be carried out to help choose the right materials. The lack of knowledge of the surface hardness characteristics of some materials that support the structures could produce large faults, which is why this type of study is necessary [2].

The hardness tests most commonly used for metallic materials are static penetration methods, such as Brinell, Rockwell and Vickers [3], due to the simplicity of their performance and the small amount of time required for a measurement [4]. The procedure for measuring Brinell hardness is defined by the ISO 6506 series of standards [5], so in this method a device known as a penetrator is used to print a fingerprint on the analyzed material. Once pressure is applied to the media, the diameter of the impression is measured with a microscope or laser scanner to give the result of the hardness [6].

The Rockwell method is governed by ISO 6508 [7], in this case the penetrator is pushed against the material with a pre-set force. Once the penetrated apparatus reaches equilibrium and the initial force has been reached, a force majeure is applied and the difference in penetration between the first and the second force is measured, the result of which is the level of hardness of the material [8]. The drawback of this test is that the penetrator travel is limited to 100 Rockwell points or 0.2 millimeters. This limitation requires different combinations of test force and forms of penetration to accommodate the hardness of all possible materials to be tested [9].

Finally, the Vickers method is considered as the universal hardness measurement method and is considered as an improved version of the Brinell method [10], this test is governed by the ISO 6507 standard [11]. To carry out this test, the material to be studied must be prepared beforehand, the pressure to leave a mark is applied and once it is formed it is observed in a microscope, the diagonals are measured, and an average is obtained, which is the level of hardness [12].

The main contribution of this article is to carry out an analysis of the hardness behavior of ASTM-A36 steel both in the supply state and after different cutting

processes, to study the effect that these have on this mechanical property of materials widely used in the industry.

2. Methodology

The steps used to measure the hardness of materials are presented below, together with a detailed description of the instrument used to measure this mechanical property and the detailed steps taken in the study.

2.1 Steps for hardness measurement

The Rockwell test is a quick and easy method to perform but less precise than other tests, in this case the hardness is obtained according to the depth of the footprint and not the surface as in the Brinell and Vickers tests. To perform this test, the first step was to apply a 10 kg load to the penetrator (ball or cone), which causes a small footprint on the surface of the material to be tested; the depth of the footprint, h_1, is measured and taken as a reference, setting the machine's comparator to zero.

After that, the load on the penetrator was increased to 90 kg if it is a ball penetrator, or to 140 kg if it is a cone penetrator, which was maintained for a period of between 1 and 6 seconds, and then the depth of the fingerprint was measured h_2.

Finally the charge was removed, so that the material tried to recover its initial position leaving a permanent mark of a depth h_1+e.

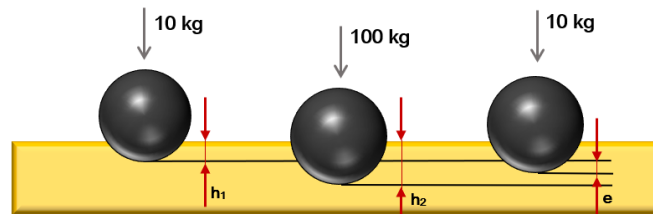Figure 1 describes the procedure explained above.

Figure 1. Rockwell test.

Rockwell hardness is not expressed directly in units of penetration, but as the difference between two reference numbers, as described below.

$$HRC = 100 - e, \tag{1}$$

and

$$HRB = 130 - e. \tag{2}$$

2.2 Hardness measuring instrument

For hardness measurement the instrument used is usually a universal hardness testing machine or hardness tester, which performs one or more of the hardness measurement methods and provides accurate results. There are different types of

hardness testers according to the different families of materials, with the possibility of measuring hardness in soft materials such as rubber and hard materials such as steel.

The first hardness tests were based on the behavior of the minerals according to their ability to scratch a softer mineral. For this purpose, a scale called Mohs was defined, with values ranging from 1 to 10, where 1 represented talcum powder and 10 represented diamond. The Rockwell differential depth hardness tester measures the effects of heat treatment on deep groove ball bearing raceways. The scales used with this technique are varied according to the different combinations of penetrators and loads that are used, being able to test any metal or alloy, both hard and soft. There are two types of penetrators, the spherical hardened steel ball penetrators with standard diameters and the conical diamond penetrators. The hardness measurement method consists of first applying a small initial load, which increases the accuracy of the measurement, and then a higher load. Based on the magnitude of the higher and lower loads, there are two types of tests: Rockwell and Rockwell surface tests. The loads used for both tests are specified in Figure 2.

| Ensayo | Penetrador | Forma del penetrador | | Carga |
		Vista lateral	*Vista Superior*	
Rockwell y Rockwell superficial	Cono de diamante	$120°$		60 kg 100 kg 150 kg Rockwell
	Esferas de acero de $\frac{1}{16}, \frac{1}{8}, \frac{1}{4}, \frac{1}{2}$. Pulgadas de diámetro			15 kg 30 kg 45 kg Rockwell superficial

Figure 2. Types of penetrators and fillers in Rockwell and Rockwell surface tests.

2.3 Hardness test

To perform hardness measurements on the specimens, an AFFRI 250 DRMC hardness tester was used as shown in Figure 3a, which is part of a family of semi-automatic hardness testers for Rockwell, Rockwell, Rockwell, Brinell and Vickers surface hardness tests according to ASTM, ISO and JIS standards, which are hardness tester with an excellent quality/price ratio, guaranteeing precision and reliability.

In this equipment the forces are applied by means of a system of load cells in the same axis as the penetrator, and the load is always applied with the maximum precision, which eliminates the problems associated with dead weights and the guarantee of stability over time. These hardness meters need not be at the same level and are unaffected by any external source of vibration, allowing hardness testing on all metals such as iron, steel, hardened steel, cast iron, brass, aluminum, copper and metal alloys.

To collect the data, the hardness scale was first selected, then the hardness tester was calibrated with the calibration standard block, shown in
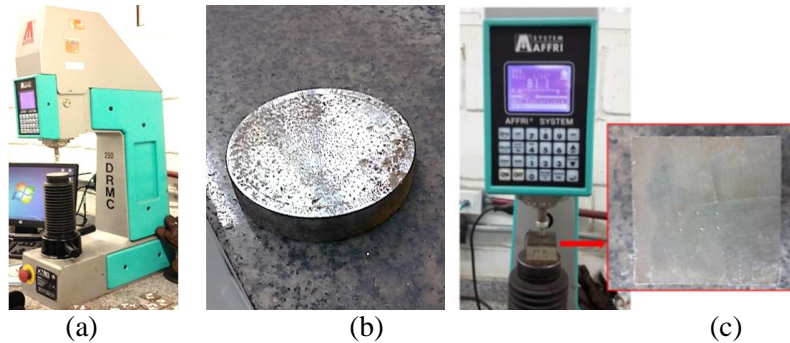Figure 3b, and finally the measurements were performed on the specimens, six on each one, as shown in Figure 3c.

(a) (b) (c)

Figure 3. Measuring equipment, a) Durometer AFFRI 250 DMRC, b) Calibration standard, c) Hardness measurement.

3. Results and discussion

3.1 Hardness results

In order to be able to clearly observe the hardness behaviour of each test specimen, an individual average hardness was calculated taking into account the values obtained from the six hardness measurements. This value indicates the hardness of each specimen. A general average hardness is also calculated for each cutting method, which is calculated on the basis of the individual hardness averages of each specimen. This value indicates the value of the average hardness generated by each cutting process on the surface of the material as shown in Figure , allowing a comparative study between the individual hardness averages of the specimens for each cutting method.

 It can be seen that the hardness obtained after plasma cutting is always higher than the hardness obtained with the other cuts and the specimen without cutting with a notable difference. In the case of specimens with milling, cutting and oxy-cutting cuts, a similar behaviour can be observed, and in the case of specimens with wire cutting, the first two specimens show a reduction in hardness compared to the material being supplied and then a slight increase compared to it.
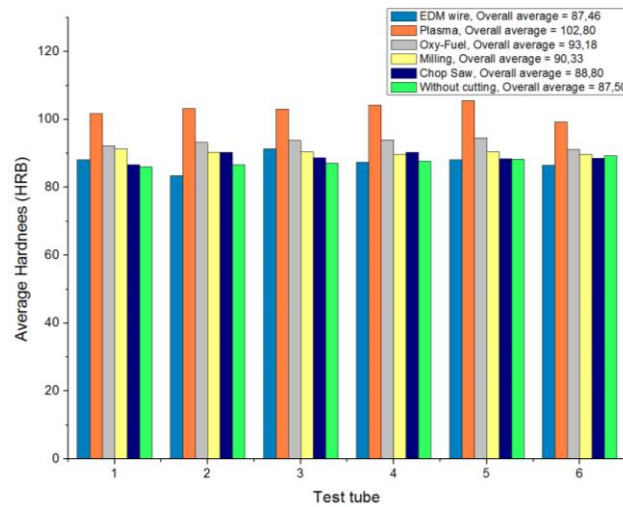
Figure 4. Comparison of individual hardness

The increase in the hardness of the steel is due to the fact that they can be
hardened by dispersion, controlling the size of the perlite, since the steel is
initially heated to produce homogeneous austenite, a step known as austenization,
and the annealing allows the steel to cool slowly in the furnace, producing coarse
perlite. The normalizing process allows the steel to cool more quickly, in the air,
producing fine perlite, which has a higher mechanical resistance.
Figure shows how the hardness of the specimens varies compared to a specimen
without a cut, whose average hardness was calculated at 87.68%.

Types of cutting	Average general hardness	Variation in hardness (%)
Oxyfuel	93,18	6,27
Milling	90,33	3,02
Chop Saw	88,80	1,27
Plasma	102,80	17,25
EDM Wire	87,46	-0,26

Figure 5. Variation in hardness compared to a specimen without cutting.

3.2 Economic Study

Figure shows the commercial costs of each of the cuts made in Colombian pesos,
where yarn cutting is expensive because the equipment used in the trade is rare
and expensive, while the other cuts are more affordable and can be found for
moderate costs. Plasma cutting also requires special equipment but is more
common than the wire-cutting machine and due to the machine's configuration
allows large lengths of material to be cut in a single operation.

Types of Cutting	Cutting Value	Observations
Oxyfuel	$ 30.000	Value for 6 specimens
Milling	$ 70.000	Value for 6 specimens
Chop Saw	$ 30.000	Value for 6 specimens
Plasma	$ 12.000	Value for 6 specimens
EDM Wire	$ 225.000	Value per hour $150.000, cutting time 80 min approx..

Figure 6. Costs of the cutting process (Colombian currency).

Analyzing the variation of the hardness of each of the cuts with respect to the hardness of the material in supply state and the cost of the cutting process, we can observe that the cutting processes with a cutting machine and a milling machine produce an increase in hardness values of 1.27% and 3.02% respectively, which can be considered as a slight variation and affects very little the value of the hardness of the material in supply state and both processes are of low cost and easy access in the industry. The wire cut presented a decrease in the hardness of the material by 0.26% with respect to the initial hardness of the material, this variation is very slight and maintains practically the same hardness as the initial state but the cost of the cutting process is very high with respect to all other cuts and the process is difficult to access in the industry. The plasma and oxyfuel cutting processes showed an increase in hardness of 17.25% and 6.27%, respectively, generating a considerable increase in this property, which may affect the desired result of the material depending on the final application for which it is required. However, both cuts are very low cost and easy to access in the industry.

4. Conclusions

The results obtained allow to observe variations in the hardness of the material, being evident the tendency to increase the hardness of the specimens subjected to higher temperatures during the cutting process, it is also remarkable that the wire cutting by EDM resulted in a slight decrease in the hardness of the material with respect to the hardness in the state of supply or without cutting. Taking into account the costs that are presented when performing each of the cutting processes and comparing them with the hardness observed in each of the specimens, it was established that the cutting processes with cutting machine and milling machine are the ones that present the best cost-variation relation for this property, in addition, they are very low cost and easy to access processes in the industry.

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