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Experimental Study of the Cutting Processes on the Microstructure of an ASTM A36 Steel

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Abstract

This article analyses the microstructure of ASTM-A36 steel both in its delivery state and after various cutting processes. The material was cut with some methods conventionally used in the metal-mechanical and construction industry, in addition to other non-conventional processes used to a lesser extent in the same industry. Similarly, 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, oxy-cutting and cutting machine, while the unconventional cuts applied were the wire by EDM and plasma, maintaining as far as possible similar cutting and working parameters. Subsequently, the cut surface of each of the specimens was analyzed and microscopic images of their microstructure were taken, from the results differences were established and it was defined which of the cutting methods used had the greatest effect on the material.

Keywords: Microstructure, Metallography, Cutting processes

1. Introduction

The subject of mechanical material testing is an important aspect of engineering practice. Today, more attention is being paid to interpreting test results in terms of service performance, as well as giving reliable indications of the material's ability to perform certain types of duties. Mechanical testing is also used in research to obtain data for designing purpose [1].

Metallography is the branch of metallurgy that studies the structure of a metal-alloy and relates it to its chemical composition, mechanical and physical properties. It consists of carrying out a study of the microstructure of a material, as well as obtaining other information such as grain size, grain boundaries and characteristic phases of the material [2]. In the early days of metallurgy, they were used to determine the physical and mechanical properties of materials, chemical analysis and mechanical testing, but with these methods the metal or alloy was not completely defined [3]. With the appearance of metallography, valuable information began to emerge regarding the shape and size of grain, hardness, tensile strength, resilience, fatigue, among others, which can be modified by heat treatments or mechanical shaping. Metallography does not replace the methods mentioned above, but rather they complement each other [4].

The mechanical properties of an alloy depend not only on its chemical composition, i.e. the percentage by weight of each element, but also on how it is presented. Thus, for example, the chemical elements forming an alloy can be found in the form of a homogeneous solid solution, in the form of a eutectic mixture, in the form of an intermetallic compound of defined chemical composition, dispersed within a solid solution, among others [5]. Each of these components is called a metallographic constituent and its proportion, shape and extension depend to a large extent on the properties of the alloys, which are detected under the microscope and their recognition constitutes the micrographic analysis of the alloy [6].

The ASTM E3 standard for the execution of metallographic tests determines the appropriate dimensions for the specimens, in addition, it specifies in the use of a standard specimen and how the dimensions can vary within the specific limits [7]. The main means of preparing metallographic samples is mechanical in nature and consists of three distinct stages: sectioning, assembly and grinding or polishing. However, products and procedures vary widely for different applications [8].

Authors such as Jen et al. [9], studied the behavior of the microstructure of ASTM A36 steel when exposed to fire, thus replicating the possible fires that can occur in buildings, since the material in question is highly employed in the construction industry, all with the aim of rebuilding the spread of fire. On the other hand, Puri and et al. [10], studied the behavior of the microstructure when the surface was exposed to wire cutting by EDM, in this case the material was not exposed to high temperatures.

2. Methodology

For the metallographic test, instruments and supplies were needed, such as a polisher, a metallographic polisher, sandpaper, aluminum oxide powder, dryer or blower and a metallographic microscope, some of which were shown in the Figure 1.

a) b) c)

Figure 1. Inputs and instruments. a) metallographic polisher, b) metallographic microscope, c) blower.

The correct preparation of the specimen for microscopic observation is of fundamental importance, for this reason the first step was to select the place from which the sample would be taken, a large part of the success of the study depends on this. The assembly ensured that the sample was held firmly, properly and securely in place during both manual and automatic polishing. In addition, it contributed to the fact that the edges of the sample were not exposed to being destroyed by the action of abrasive materials. In addition, rounded edges were avoided.

The surface of the specimen chosen for the observation was first flattened by coarse grinding using a grade 80 sandpaper, then the grinding was gradually refined using grade 120, 240, 400 and 600 sandpaper, all this procedure was carried out with a sanding disc speed of 250 rpm and for a time of 45 seconds. Subsequently, a mechanical polishing process was carried out to remove all the fine scratches produced during the roughing process and thus obtain a specular surface. The abrasive used for this procedure was aluminum oxide, for its preparation a small amount of abrasive was mixed in one liter of water, stirred with a glass rod to obtain a homogeneous mixture and allowed to decant for about 30 minutes. Then the liquid was drained with the rust in suspension, avoiding dragging the coarser decanted material, thus obtaining an oxide under conditions of use, with the powder of aluminum oxide the surface was polished, with a speed of the disk of 120 rpm during a time of 180 seconds until obtaining a mirror-like surface, as shown in Figure 2a.

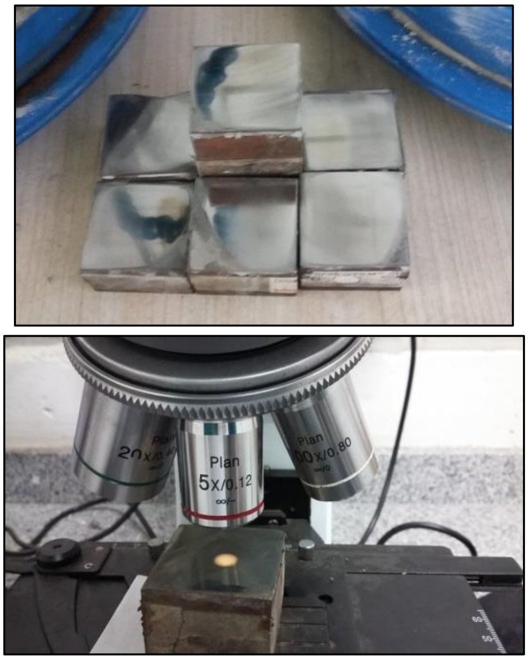


Figure 2. Material, a) Polished specimens, b) specimen analyzed under the microscope.

Next, the chemical attack was carried out with a concentration of 3%, for a period of 30 seconds, with the objective of highlighting the structure of the metal. A cotton swab soaked in the reagent is passed over the polished side, then the test tube is washed with water, rinsed with alcohol or ether and dried in a stream of hot air. Finally, the surface was observed under the microscope, as shown in the Figure 2b.

3. Results and discussion

The result obtained from the microstructural metallographic test on each specimen is described below, for which a representative sample of the specimen surface has been selected. The plasma cutting generated a considerable variation in the microstructure, which is reflected in the observed increase in the hardness values of the material, Figure 3 shows the microstructures of the uncut specimen and the specimen subjected to plasma cutting.

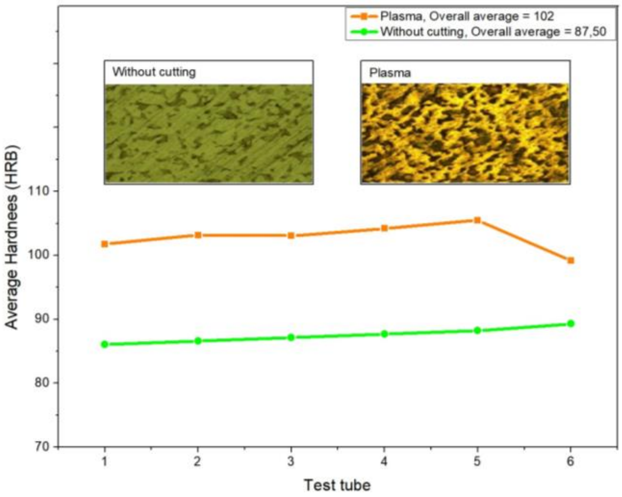


Figure 3. Hardness and micrographs, specimens without cutting and plasma cutting.

The cuts made with the cutting machine and wire by EDM affected very slightly the microstructure of the material, because of which the hardness remained close to the value obtained in the specimens that were not cut, Figure 4 shows the hardness behavior and the micrographs of the specimens subjected to these cuts.

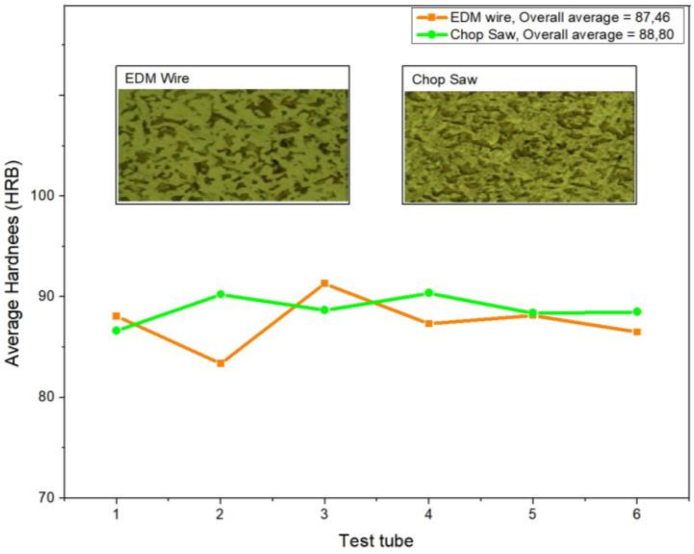


Figure 4. Hardness and micrographs. Chop Saw and EDM Wire.

On the other hand, oxyfuel cutting resulted in a notable change in the microstructure of the specimen, however, the hardness obtained was not much greater than that of the specimen in the delivery state. Figure 5 shows the microstructures and hardness behavior of the specimens subjected to oxyfuel cutting and milling.

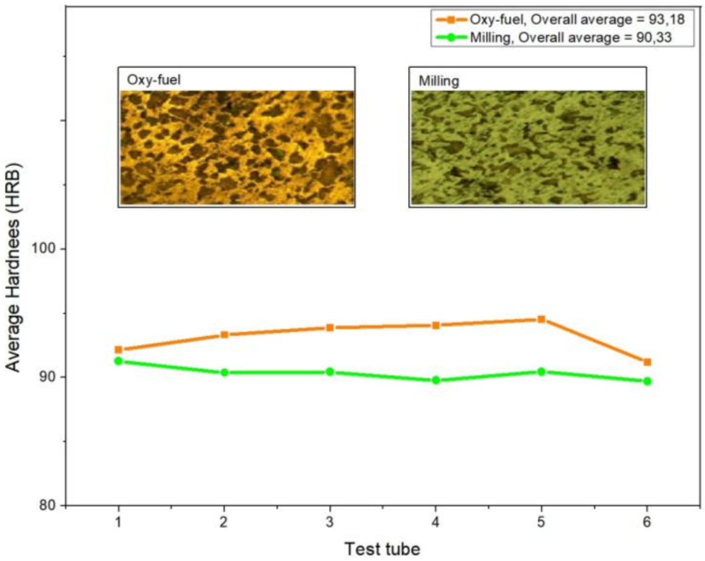
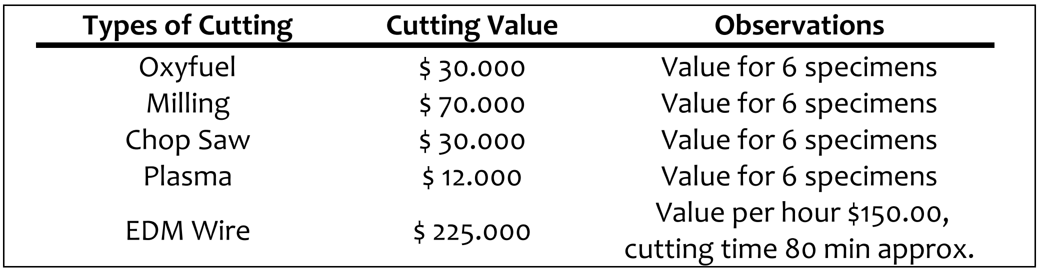


Figure 5. Hardness and micrographs. Oxy-fuel and Milling.

The microstructure of the uncut specimen that was taken as a basis for the comparison shows a matrix of ferrite and perlite, where the ferrite is the lightest colored area and the perlite is the darkest colored area. When cutting the material with the milling, cutting and EDM wire cutting processes, it is observed that the microstructure of the material is not affected, since the ferrite and perlite matrix is maintained. On the other hand, when cutting the material with the plasma cutting and oxyfuel cutting processes, a variation of the microstructure is observed, this since the material has been heated to a temperature higher than 750 ºC, during this heating only austenite remains in the microstructure, when the material begins to cool just below 750 ºC the ferrite is nucleated and grows, usually at the edges of the austenite. The ferrite continues to grow until the temperature drops to 727°C and the remaining austenite is surrounded by ferrite, at this temperature it has already changed its composition, a subsequent cooling below 727°C causes all remaining austenite to become fine perlite.

The final microstructure contains islands of fine perlite surrounded by ferrite, this structure makes the alloy resistant due to the fine perlite hardened by dispersion and at the same time ductile due to the ferrite.

Figure 6 shows the commercial values of each of the cuts made in Colombian pesos, where wire cutting by EDM presents a high cost since the equipment used is not very common in the trade and is of a high cost, on the contrary, the other cuts are more accessible and can be found at a lower cost. It is important to note that plasma cutting also requires special equipment, however, it is more common than the EDM wire cutting machine and due to its configuration allows cutting large lengths of material in a single process.



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 $150.00, cutting time 80 min approx.

Figure 6. Costs of the cutting process

By comparing the microstructure of the specimens after each of the cuts with respect to the microstructure of the material being supplied and the cost of the cuts, it is determined that the cuts with milling and cutting machines are better suited to the requirements they affect the material to a lesser extent and are very common in the industry and at a lower cost.

4. Conclusions

Characterization of the effect of different cutting methods on the microstructure of ASTM-A36 steel was carried out. From the results obtained for each of the cuts in the different tests, it was possible to establish which cutting method most affects the microstructure of the material.

In the metallographic test, a surface preparation was performed, and acid was applied to it as established in ASTM standard E3-01. Subsequently, each of the specimens was analyzed with a duly certified metallographic microscope and the micrographs shown above were obtained. From this procedure he determined that the cuts with a milling machine, a cutting machine and an EDM wire had a very slight effect on the microstructure of the material. In contrast, plasma cutting and oxyfuel cutting generated a variation in the microstructure of the material, which led to an increase in the surface hardness of the material.

Considering the costs involved in performing each of the cutting processes and analyzing the results obtained from the metallography, it was established that the cutting processes with the cutting-off machine and the milling machine are those with the best cost-variation ratio, since after these cuts the microstructure of the material is maintained in a state of supply and are very low cost and easy to access processes in the industry.

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