COMPARISON OF FORGING WITH RAW MATERIAL RESULTED FROM ROLLING AND INGOT CASTING WITH AND WITHOUT ELECTROMAGNETIC STIRRING THROUGH METALOGRAPHY AND NON-DESTRUCTIVE TEST

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Abstract. *The objective of this work is to use metallographic and non-destructive tests to compare hot forged steels to the production of flanges resulted from the steel manufacturer with the same chemical composition (0.25%C, 0,19%Si e 0,60%Mn) however, with three kinds of supply: rolling, ingot casting with and without electromagnetic stirring. The forged pieces were analyzed through transversal and longitudinal cuts of the three kinds of forged in the same manufacturing conditions. The tests used in this comparative study and the observed differences were made through metallographic study (macrograph of transversal and longitudinal cuts and micrograph in different points of deformation in each forged piece) and with the penetrating liquid non-destructive test.*

Keywords*: Steel, hot forging, electromagnetic stirring*

1. INTRODUCTION

The hard iron, when heated from ambient temperature, changes its centered cubic body (CCB) structure to centered cubic face (CCF) in 912 °C. With the heating up to 1394 °C the structure changes again into (CCB). This variation occurs as the temperature increases with consequent increasing of the atomic vibration, defining the packaging factor to measure the volumetric density of the unitary cell. Consequently, the volume occupied by atoms inside the unitary cell is defined (Silva and Mei, 2006).

When two metals are mixed up to form a hard solution, the atoms of solute can substitute a fraction of atoms from the die (substitution hard solution) or allocate themselves in the empty space of the die (interstitial solid solution). To form the steel, carbon atoms are needed to unite to the iron. It occurs in an interstitial way, because there are atomic radiuses in the carbon atoms smaller than the iron atoms to be substituting (Silva and Mei, 2006).

In metallurgy it is observed that mostly the absolute majority of available metals in nature in the form of ores, that is, combined with other chemical elements and in an oxide way must have the same extraction and purifying way with oxide-reduction. It occurs because the iron is not found in nature in the elemental form, but it is always combined with sulfur or oxygen through the most common ores as hematite (Fe_2O_3) and pyrite (FeS_2) (Chiaverini, 1986).

In the production of steel, four stages are well defined: high furnace, steel mill (pig iron impurities deoxidizing and impurities oxidation), leakage and pouring, and finally rolling. The steel is produced basically through iron ore, manganese ore, coal and limestone. Among these, limestone detaches slag from pig, manganese ore is desulfurized and deoxidized, and coal or coke is combustible and redactor (Colpaert, 1974).

Mostly metallic products, except the ones produced by electro deposition and powder metallurgy, pass through a transformation in some stage of its production, from liquid state to hard state. The structure formed immediately after the solidification determines the final properties of the products, not only in case of cast products, which are used in as-cast state, but also when these products are manufactured later for the production of bars, plates and wires. However it is believed, incorrectly, that the flaws are eliminated during the subsequent mechanical forming, it is very dangerous to ignore the existence of macro-segregation, of contraction pores, nonmetallic inclusions, and other flaws in the ingots (Li, 1998).

2. ELECTROMAGNETIC STIRRING AND ROLLING

Applications of electromagnetic stirring on the manufacture of steel have become one of the most promising control methods regarding liquid steel flow and its movement particles in the production of steel pieces in various engineering applications. The electromagnetic stirring, established as a high efficient technique, can reach efficiency and confidence in the manufacture of steel, which can find the metallurgical objective of improving the steel quality and productivity during its melting. This process has been widely accepted in conventional practice for using electromagnetic stirring in the manufacture of continuous casting ingots with the objective of controlling initial solidification to reduce various defects and improve the equiaxial grains zone in the solidification during continuous casting (Yu and Zhu, 2009).

The stirring is the simplest route to prepare the manufacture of steel in casting mold. This concept is based on the stirring of liquid steel in a way to undo the primary dendritic structure and the formation of an equiaxial microstructure. With the effect of stirring, and due to their power cut down, the dendritic arms bend, they have plastic deformation and fragment themselves, which explains the multiplication of grains (Nafisi *et al*, 2009).

The material solidification in the steel manufacture embraces important details which will make a great change in the piece that will be manufactured and mechanically requested in its use. Some solidification topics should be known before the forming process of this material is done, searching for it or forming group pieces integrity. In the metal-mechanic industry, the pieces demands with different requirements and proprieties are much more requested without defects and intern stress harmful to the structure and mechanical proprieties compatible to responsibilities expected on service. The mechanical characteristics of a piece in work, or the line of conduct of a material, during the different stages in the process, such as the forming, machining and heat treatment steps, depend, fundamentally, on the internal characteristics of the original piece (Chiaverini, 1982).

In continuous casting, the electromagnetic stirring is used to decrease the columnar grain size that is harmful to steel and was originated in its solidification. The control of the solidifications line of conduct through the use of the stratagems to improve the structure of the steel in its solidification has been gradually implanted in the industry of steel manufacture. The solidification describes the phenomenon of liquid turned into solidified materials as a result of the way of control and the guidance of the temperature increase in the liquid state, and with electromagnetic stirring as an alternative to diminish the size of the columnar grains. In this way, the magnetic fields that diminish the convection during the reduction of temperature in the liquid state and the material behavior in its solidification have been successfully applied as material casting control in the structuring of more equiaxial grains (good for steel proprieties) and smaller columnar grains (harmful for the structuring and equilibrium of the steel proprieties) (Stahlberg[a], 1986).

After the continuous casting stage, the rolling stage follows. It consists on hot straining through rolling rolls with gradual reduction in the dimensions of the ingot to change little by little the structure of the material.

The rolling results and benefits are meant to be widely used in mechanical forming, due to the dynamic and static recrystalization that culminate in an objective structure obtained with minimum defects resulted from steel solidification during continuous casting. The way the curve “tension x deformation” is followed and changed since its dynamic recovery until the dynamic recrystalization (Du *et al*, 2006).

3. HOT FORGING PROCESS

In general, the non longish semi finished metallic products are produced through metal forming by processes such as hot forging. In this process, there are some stages like heating which aims at the homogenizing of the micro structure for, next, in the deformation stages, the product be turned from a simple geometry to another complex geometry. This transformation occurs through dies and penetration punches that determine the product geometry (Gentile *et al*, 2002).

The elements involved in this process (dies, punches, material to be forged) and their characteristics should ensure the material fulfilling and adequate flux in the die which is being forged, so that the hot forging practical operations occur with the minimum external and internal defects in the piece. In order to the process occur in an optimized way, it must have the knowledge of the material resistance to the plastic flow and its capacity to flow, that is, its flow tension, its forgeability, the friction, the cooling effects in the contact between the die, the punch, and the material that is being forged (Altan *et al*, 1999; Schaefer, 2001).

4. NON-DESTRUCTIVE TEST THROUGH PENETRATING LIQUID AND MACROGRAPHY

Due to the basic characteristics of the penetrating liquid test, it can be applied in a great amount of metallic and nonmetallic, ferrous and nonferrous products, being forged, melted and ceramic of a high density, since they are not porous with technical and economically satisfactory results in the revealing of superficial discontinuities. It can be applied during the manufacturing process, at its end or during maintenance, to detect the arising of the discontinuities in use.

The penetrating liquid is applied with brush, pistol, or with aerosol can or even immersion on the surface to be tested, which consequently works during a penetration period. The removal of this penetrating from the surface is made by washing with water or solvent.

The application of a revealer (talcum powder) will show where the superficial discontinuities are with precision and great simplicity; however its dimensions are slightly enlarged. This method is based on the phenomenon of capillarity that is the power of penetration of a liquid in extremely small areas due to their low superficial tension. The power of penetration is such an important characteristic once the test sensibility is hugely dependent on it (ABENDE, 2010).

The macrography consists on the examination of the aspect of a metallic piece or sample, according to a flat section properly polished, and by rule attacked by an appropriate reagent. The aspect obtained is called macrostructure. The examination is done with naked eye or with the help of a loupe with the maximum enlarging of ten times to be considered macrography (Colpaert, 1974).

5. EXPERIMENTAL PROCEDURE

Through a square measuring 120mmx120mm for a forging of a kind of a flange, the raw material supplied by the steel manufacturer was used for the achievement of forged steel comparative tests resulted from rolling, and continuous casting with and without electromagnetic stirring. The tests accomplished in this work were through metallography and from the use of non-destructive test by penetrating liquids.

The aim of this proposition is to show a comparison of forged flanges that originally derived from three different conditions: steel coming from continuous casting with and without electromagnetic agitation for the forging, and steel derived from rolling for forging.

The first stage of the experimental work started from the heating at 1200°C of a workpiece of 120mmX120mmX48mm and subsequent pre-forging in press and forging for hammer process to obtain the piece with flange format. In figure 1 it is observed the forged and burred flange.

Figure 1. Forged and burred flange

The forged piece has axial symmetry and consequent different deformation degrees, which generates different structures in different places in the piece. To carry out the macrography, a longitudinal and a central cut in the forged pieces were necessary. After that, there was a rectification to prepare the forged pieces for the macrography. In fig. 2 it is observed the polishing of the cut flange before the attack.

Figure 2. Forged in cutting, properly polished to macrography

In this process a mixture of 50% of clean water and 50% of HCl (concentration 37%) were done for the attack to the polished surface. In picture 3 the macrographies of forged steel derived from rolling are observed, from continuous casting with electromagnetic stirring, and without electromagnetic stirring. In this picture is observed a better organization of grains in the rolled, because it normally goes through a rolling thermomechanic work before the forging. The steel with stirring shows the fibering lines more organized than the one without stirring, showing that electromagnetic stirring plus forging thermomechanic work had a favorable result in this sense of comparison.

a) b) c)

Figure 3. Macrography of three types of forged: a) rolled, b) with electromagnetic stirring e c) without electromagnetic stirring

For the observation of granulation, micrographies were done with an increase of a 100 times in the electronic microscope and chemical attack with 2% nital concentration. The evaluations of these results were established, mainly, in the effect of the hot forging thermomechanic work done in three pieces, and in the effect of the electromagnetic stirring. In fig. 4, the recrystalized granular structure of the forged coming from rolling is observed; it is the best elimination situation of dendritic structure, since it has been through two thermomechanic works (rolling and forging).

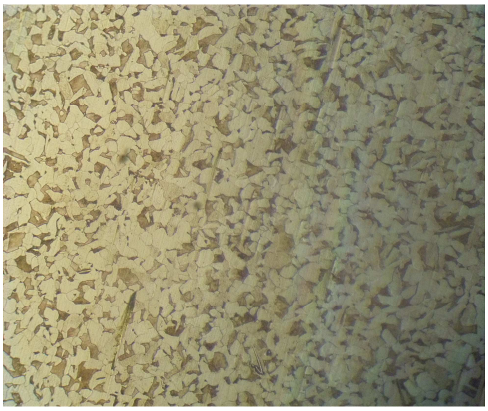

Figure 4. Recrystallized granular structure of forged coming rolling

In fig. 5, it is observed the granulation of the forged steel coming from ingot casting with electromagnetic stirring, where a high quantity of recrystalization and elimination of the primary dendritic structure due to the process of electromagnetic stirring is seen, although it does not have the same quality of recrystalization compared to the one coming from hot rolling.

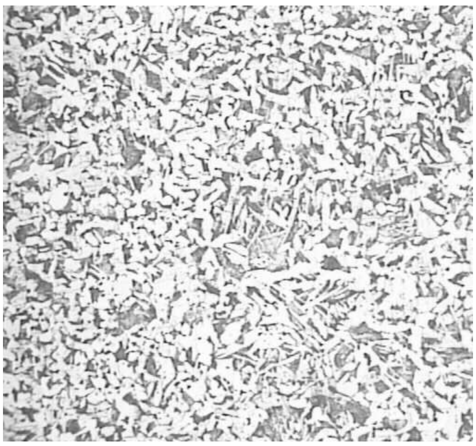

Figure 5. Micrograph of steel coming from the ingot casting with electromagnetic stirring

To finish the micrographic analysis, the third steel derived from the ingot casting without going through electromagnetic stirring process showed that despite going through a hot forging thermomechanic process, like the two mentioned before, it did not show a great degree of recrystalization, still showing a dendritic structure a lot emphasized. In fig. 6, it is observed the micrograph with an enlargement of a 100 times of the forged steel derived from the continuous casting, which did not go through the electromagnetic stirring in its manufacturing as a raw material for the forging.

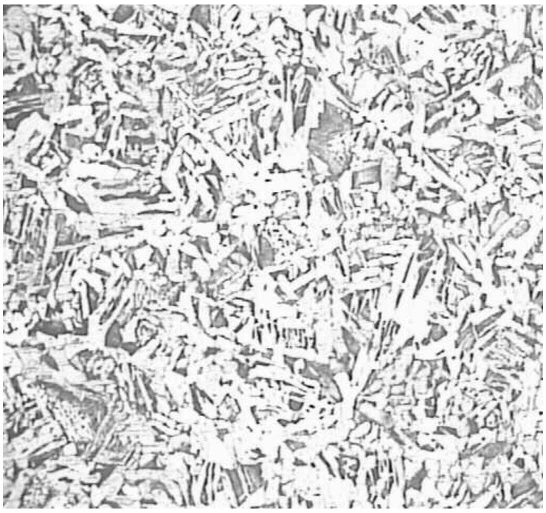

Figure 6. Micrograph of steel coming from the continuous casting without electromagnetic stirring (increase in 100x)

As second analysis among the three types of steel studied in this work, penetrating liquids non-destructive test was done in the stirring and non stirring forged, since the laminated in a big group of forged of low carbon steel does not, normally, present defects. The procedure to evaluate if there were pores or surface checks derived from the rolling processes followed the technique 2C (coloring removable in solvent). In fig. 7, there are some products used in the process, which has the use in the first wiper stage for surface cleanliness that has a 5-minute evaporation time.

Figure 7. Products used in the penetrating liquids non-destructive test

After this stage, there was the use of the penetrant in the whole surface of the piece interest with a penetration time of 10 minutes. In fig. 8 it is observed the penetrant applied in the whole polished surface of the forged piece derived from the stirring and non stirring.

Figure 8. Penetrant in all parts of the section

After the time of penetration for the total removal of the penetrant, slightly wet clean remover cloths were used. Past 5 minutes after the total removal of the penetrant, the developer was applied in a gradual way in both pieces with and without electromagnetic stirring. Past 20 minutes after the developer application to get the final conclusion. Figure 9 shows the result without pores and checks of the forged piece derived from the ingot casting with electromagnetic stirring.

Figure 9. Revelation of the forged piece derived from ingot casting with electromagnetic stirring without apparent defects

The same procedure was applied for the forged derived from the ingot casting without electromagnetic stirring. Discontinuities were found according to fig. 10 in red, thus validating the electromagnetic stirring.

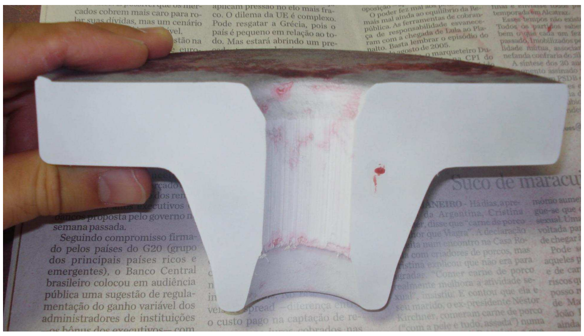

Figure 10. Revelation of the forged piece derived from ingot casting without electromagnetic stirring with discontinuity found

6. CONCLUSIONS AND RESULTS

In the metallographic comparisons of the three kinds of forged, the following results were reached. The macrography showed the confirmation of an homogenic structure distributed along an analyzed section of the forged piece derived from the rolling; the one with electromagnetic stirring showed a guidance of the constant fibering lines while the one without showed a lot of irregularity in the lines and in the visible structure. In the micrograph, in the piece derived from rolling recrystalized grains were observed by the forging and thermomechanic rolling work; the one with electromagnetic stirring showed a good quantity of recrystalization and a good elimination of the primary dendritic structure, while in the forged derived from the ingot casting without the electromagnetic stirring there was a great amount of dendritic structure, despite the hot forging thermomechanic work it went through, in this way, eliminating the piece.

With the use of penetrating liquids, the forged derived from the ingot casting with and without electromagnetic stirring, due to the positive historical of the tests in the forged pieces derived from rolling and also to the positive example for it has recrystalized grains and uniformity. With a 100 times enlargement in the microscope and proper attack, it was observed in the steel with stirring a convenient degree of recrystalization to be compared to the rolling one, while the one without stirring showed a lot of dendritic structure, despite the forging thermomechanic work, thus eliminating the piece at this stage of evaluation and comparison.

The electromagnetic stirring in the manufacture is an alternative for a better steel quality in the continuous casting in relation to a reduction in the amount of discontinuities. Through some tests as metallography and penetrating liquids non-destructive tests, it was possible to identify a better quality of forged derived from the ingot casting with electromagnetic stirring approaching the steels derived from rolling. The possibility to use this kind of steel for forging is more economical to the forging and also to the steel manufacturer, because this would avoid the rolling stage.

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