Review on the Microstructure and Microhardness of Extruded Aluminum Alloys

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***Abstract* - The review of different research done on the microstructure analysis over the past years is done in this paper. Review is done to gain precise knowledge about microstructure and its analysis. How the microstructure is changes throughout the extrusion process is discussed. It is qualitative review of microstructure analysis so this paper does not include any experimental value. The influence of heat treatment on the microstructure and mechanical properties is also included. Also the details about the microhardness are given in this paper. The various types of microhardness test are also explained. The procedure of measuring the microhardness is also explained. The detail of Knoop hardness test and the Vickers hardness test are given in this paper also.**

Index Term **– Microstructure, aluminum alloys, microhardness, Vickers microhardness test.**

I. INTRODUCTION

Aluminum alloy has wide range of chemical composition and product forms which can be manufactured by all available metal working techniques and casting process. It is the widely used metals in the construction, transportation, electrical sensor and packaging. All commercial aluminum alloys contain some iron and silicon as well as two or more elements intentionally added to increase the properties. In the extrusion of recrystal alloys, the mechanical proprieties of the profile are of great interest, in particular strength and deformability of profiles for transportation industry. The term extrusion is usually applied to both the process, and the product obtained, when a hot cylindrical billet of aluminium is pushed through a shaped die. A heated billet cut from DC cast log is located in a heated container, the actual temperatures of both varying according to alloy and other operation conditions usually around 450 °C - 500 °C. At these temperatures the flow stress of the aluminium alloys is very low and by applying pressure by means of a ram to one end of the billet the metal flows through the steel die, located at the other end of the container to produce a section, the cross sectional shape of which is defined by the shape of the die. During the whole thermo-mechanical process, different metallurgical phenomena take place: static recrystallization SRX, dynamic recrystallization DRX (partially), geometric recrystallization GDRX, grain growth and particle precipitation.

II. MICROSTRUCTURE

In the recent years importance of analysis and prediction of microstructure in extrusion processes of aluminum alloys has increasing. The final microstructure of the as-extruded material may be influence by each manufacturing process from casting to extrusion. So the final property of the products after cold work and brazing may also be influenced. The as-extruded microstructure depends on the starting chemistry and the through profile thermo-mechanical history experienced during the extrusion. The mechanical proprieties of the profiles are mostly related to the microstructure evolution of the alloy during the whole production cycle, from billet casting to profile aging. The well-executed chain of steps developed by scientific understanding and practical experience are required to check the microstructure of aluminum and aluminum alloy. The preparation of specimens required the series of steps which are sectioning, mounting, grinding and polishing. Sometimes to obtain a small piece for examination sectioning is required. In some cases mounting of specimen is not required. Before etching surfaces should be examine. A material microstructure can also give a valuable insight into its properties and corrosion resistance. The volume fraction of inclusions and grain size are important characteristics that can affect several different material properties. A greater number of inclusions within a material can increase its strength as they can cause dislocation pile-ups. Coarse intermetallics precipitation, precipitate free zones (PFZ), grain size distribution and coarsening (Humphreys et al., 1995) are some examples of problems related to recrystal alloy metallurgical evolution that could lead to poor product proprieties at the end of the production sequence [1]. In the recrystal alloy processing, and in particular in the 6XXX series, the grains are strongly deformed on a principal direction due to the process strains, thus producing a high contraction of the grains in the other direction; when this thinning reaches the dimension of subgrains, each subgrain becomes a new grain. This phenomenon is usually called Geometric Dynamic Recrystallization (GDRX), and its mechanics is quite different from standard dynamic recrystallization where the nucleation of new grains occurs. Moreover, static recrystallization and grain growth act together when deformation ends after the die exit and the contribution of each phenomenon cannot be easily investigated.

The figure 1 shows the general microstructure characteristics of the billets in the as cast condition. The billets presented a cellular dendritic solidification mode of central equiaxed grains with an average size of 80 mm, as seen in figure 1A. It is clearly observed solute segregation in intercellular spacing and grain boundaries in figures 1.3 A and 1.3B. At higher magnifications, details of the precipitated second phases are evidenced in figures 1.3C and 1.3D. These SEM micrographs reveled needle-like intermetallic phases and Chinese-script morphologies that could correspond to the β-Al_5FeSi and α-Al-Fe-Si phases, respectively.

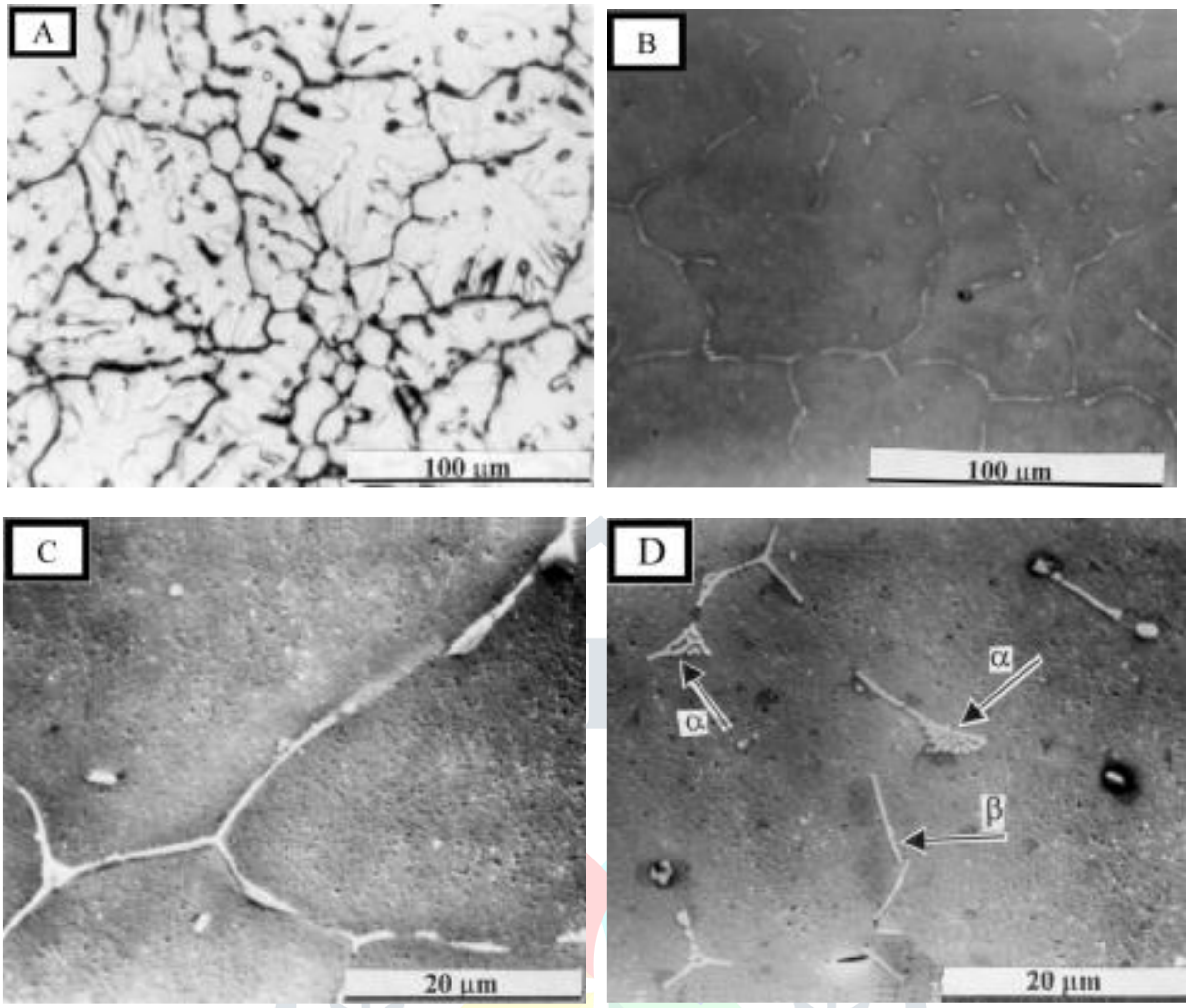

Fig.1. Microstructure of the as-cast AA- 6063, A) Cellular dendritic solidification mode (Optical microscope). B) General microstructure by SEM showing intermetallic phases at the grain boundaries. C and D) Details of the microstructure [2]

The α-Al-Fe-Si can have many variants; however in commercial alloys such as the AA- 6063, the bcc α-Al-Fe-Si with a composition close to Al_8Fe_2Si, is the most likely to form due to the presence of small amounts of Mn and also to the rapid solidification conditions associated to DC-casting.

M. Schikorra et al. in their paper they reports on prediction of microstructure on AA6060 alloy. In their research they are using experimental–numerical procedure for predicting the recrystallized structure in aluminum extrusion altogether with its validation. The whole plan was carried out in three steps: in the first step, the evolution of microstructure of an AA6060 alloy during deformation was studied by means of small-scale laboratory test, the processing parameters being chosen in order to reproduce the typical industrial conditions. In the second step, the analysis of microstructure evolution after the heat treatment was analyzed; the obtained information's was used in order to fit a recrystallization model to be implemented inside the Deform FEM code environment. Finally, in the third step, the obtained information's are applied to extrusion tests presented in another papers by the authors M. Schikorra et al on Microstructure analysis of aluminum extrusion: grain size distribution in AA6060, AA6082 and AA7075 alloys, the simulation results are compared and discussed with the experimental grain size distribution analyzed on the extruded rest.

A. Lrivas et al. studied the effect of the microstructure on the mechanical properties and surface finish of an extruded AA-6063 aluminum alloy. The microstructural evolution during homogenization of an AA-6063 aluminum alloy was carried out by optical, scanning and transmission electron microscopy as well as X-ray diffraction. The effect of the microstructure obtained after different homogenizing conditions on both mechanical properties and surface finish of the extruded products was evaluated. A good surface finish and adequate mechanical properties were achieved by a minimum homogenizing time of 6 hours.

Yuanyuan Geng reports on the microstructure evolution during extrusion of AA 3xxx aluminum alloys. In his thesis he investigate the through process microstructure evolution of aluminum alloys AA3003 (1.27 wt% Mn) and AA3102 (0.26 wt% Mn) during high temperature extrusion. He homogenized the as-cast materials for three different conditions, i.e. 500°C for 8h, 550°C for 8h and 600°C for 24h prior to extrusion. He used the Optical Microscopy to examine the behavior of constituent particles and dispersoids during homogenization. To study the evolution of the grain size, aspect ratio, and area fraction and number density of constituent particles were conducted on Back Scattered Scanning Electron Microscopy and Image Analysis with Clemex. To investigate the evolution of constituent particles during homogenization at 600°C, he heated the samples and soaked at 600°C for different times. He was found that different mechanisms of microstructure evolution occurred during homogenization including the breaking up, growth and coarsening of particles.

M. Schikorra et al. in their research they presented grain size distribution in AA6060, AA6082 and AA7075 alloys. Their research deals with the microstructure during the extrusion process AA6060, AA6082, and AA7075 alloys. They partly extruded the billet to axisymmetric round profiles. After that they considered the microstructure of the press rests consisting of the billet rests in container and die. Furthermore, these rests had analyzed to show the material flow, dynamic and static recrystallization based on macro etchings and visible microstructure under different conditions. To allow an accurate simulation of the extrusion process, punch force and temperature conditions during the tests was measured and they presented this in there paper, too.

Ayman Elsayed et al. this paper reports on Microstructure and mechanical properties of hot extruded Mg–Al–Mn–Ca alloy produced by rapid solidification powder metallurgy. They investigated microstructure and mechanical properties of hot extruded Mg–Al–Mn–Ca alloy. To optimize the processing conditions for obtaining better mechanical response both rapid solidified powders and cast billets was extruded at 573, 623 and 673 K. Powder was consolidated to prepare the extrusion billets using both cold compaction and Spark Plasma Sintering at 473 K. After that tensile property of the extruded alloy was evaluated and correlated to the observed microstructure.

Dawei Ji et al. reports on Microstructures and mechanical properties of a hot extruded Mg–4.45Zn–0.46Y–0.76Zr alloy plate. The microstructure, texture and mechanical properties of the as-extruded Mg–4.45Zn–0.46Y–0.76Zr (ZWK401) alloy plate was investigated on specimens with the extrusion direction (ED), 45° direction and the transverse direction (TD), respectively. The extruded alloy showed a mixed grain structure composed of long elongated unrecrystallized grains (LEGs) which contained both stringer LEGs and elliptical LEGs, fine equiaxed recrystallized grains (FEGs) and peculiarly arranged equiaxed grains referred as row stacked grains (RSGs). The ZWK401 alloy plate showed excellent mechanical properties in the ED sample with the UTS of 331 MPa, YS of 278 MPa and elongation to failure of 12.3%.

Zhikun Qu et al. studied the Microstructures and tensile properties of hot extruded Mg–5Li–3Al–2Zn–xRE (Rare Earths) alloys. They analyzed the extruded Mg–5Li–3Al–2Zn–xRE (Rare Earths) (x = 0, 0.5, 1.5, 2.0) alloys by X-ray diffraction, Scanning electronic microscopy and tensile tests performed at room temperature (RT) and 200°C. They also studied the Microstructure transformation and the resulting tensile properties of as-received alloys subjected to homogenization treatment. The results show that the RE addition in the alloys causes the formation of Al_2RE/Al_3RE, and they co-exist with primary α-Mg and AlLi phase in the alloys. Moreover, RE addition can improve the RT tensile properties of the alloys, while it has little effect on the improvement of elevated temperature tensile properties. Furthermore, the mechanical properties of the alloys after homogenization treatment are worse than those of as-extruded alloys.

Timothy J Harrison et al. studied differences in corrosion behaviour between 7075-T6 sheet and 7075-T651 extruded aluminium alloy. Their study involved a visual inspection of the grain structure of each material and an analysis of the grain sizes. They found that there is a significant difference in the grain sizes of the two materials; the extruded material had grains that were approximately 15-20% of the size of the sheet grains. Also, the grains in the sheet material were wider, with a length-to-width aspect ratio of 1.5. They find out that grains in the extruded material form a semicontinuous line of grain boundaries, possibly facilitating the growth of laminar intergranular corrosion and the sheet material contained higher-angle grain boundary junctions which should limit the amount of laminar intergranular corrosion produced and promote networked intergranular corrosion. They investigated the grain size and general microstructural texture through optical microscopy of cold-mounted 7075-T6 and 7075-T651 samples. They conducted qualitative comparison of inclusion shape, size and density and no measurements were taken so this comparison is based on the optical images.

Grazyna Mrowka-Nowotnik et al. studied the influence of heat treatment on the microstructure and mechanical properties of 6005 and 6082 aluminium alloys. The main objective of them was to study the influence of the cooling conditions after homogenization of the 6082 aluminium alloys. They also analyzed the effect of the solution heat treatment temperature on the mechanism and ageing kinetics of the two commercial wrought aluminum alloys 6005 and 6082. The alloys were heat treated—T4 with a wide range of solution heat treatment temperature from 510 to 580°C and then natural ageing in the room temperature. Then, Brinell hardness measurements were conducted on both alloys in order to examine the influence of ageing time on the precipitation hardening behavior. They investigated the microstructure changes of the aluminium alloys following ageing for 120 h by metallographic and transmission electron microscopy (TEM). The minor objective of their present study was to determine how extrusion processing affected the microstructure and mechanical properties of both aluminium alloys. For this purpose tensile tests were performed.

III. MICROHARDNESS

The term microhardness test usually refers to static indentations made with loads not exceeding 1 kgf. The indenter is either the Knoop elongated diamond pyramid or the Vickers diamond pyramid. The microhardness of a substance is an important parameter to define the strength of its material. This property is basically related to the crystal structure of the material or in other words, the way in which the electronic factors operating to make the structure and the atoms are packed. Physically speaking, hardness is the resistance offered by the crystal for the movement of dislocations and practically it is the resistance offered by the crystal for localized plastic deformation. Hardness testing provides useful information about the mechanical properties like yield strength, elastic constants, etc. of materials. Hardness value depends on the method of measurement that in turn determines the scale of hardness obtained. In metals an indenter is pressed into the surface and the size is measured of the formed permanent indentation mark. In certain materials, the indenter is pressed in to the material and the hardness is determined by the extent to which it had penetrated under load. In the case of minerals and brittle solids, hardness is calculated on the basis of scratch produced in one material by another of specific hardness number.

There are many methods for measuring hardness of materials but the most commonly used form of measuring hardness is the indentation type discusses an elaborate description of these methods with their advantages and limitations as follows.

Static indentation tests

In these tests, a ball, cone or pyramid is used as an indenter, which is forced into the surface and the load per unit area of the impression measures the hardness of the surface. The Brinel, Vickers, Rockwell, Monotron and Knoop tests are of this type.

Scratch Tests

In this test it is observed whether one material is capable of scratching another. If a material is able to scratch the other it is said to be harder than the other.

Plowing Tests

In these tests a blunt element usually diamond is moved across a surface under controlled conditions of load and the width of the groove and geometry is the measure of hardness. The Bierbaum Test is of this type.

Rebound Tests

In these tests, an object of standard mass and dimension is bounced from the tests surface and tile height of rebound is taken as the measure of hardness. The Shore Sceloroscop is an instrument of this type.

Damping Tests

In these tests, a change in amplitude of a pendulum having a hard pivot testing on the test surface is the measure of hardness. The Herbert pendulum test is of this type.

Cutting Tests

In these tests, a sharp tool of given geometry is used to remove a chip of standard dimensions.

Abrasion Test

In this test, hardness is defined as the resistance to mechanical wear, a measure of which is the amount of material removed under specified conditions. For example, a specimen under test is loaded against a rotating disc, and the rate of wear is a measure of hardness.

Erosion Tests

In these tests, sand or abrasive grain is made to strike the specimen under standard condition and the loss of material in a given time is taken as a measure of hardness. This method is used to measure the hardness of grinding wheels. Recent reports have shown that an ultrasonic hardness tester consisting of the modification of the Brinell indenter has been developed which enables instantaneous automatic readout using ultrasonic.

There are three types of tests used with accuracy by the metals industry; they are the Brinell hardness test, the Rockwell hardness test, and the Vickers hardness test. The way the three of these hardness tests measure a metal's hardness is to determine the metal's resistance to the penetration of a non-deformable ball or cone. The tests determine the depth which such a ball or cone will sink into the metal, under a given load, within a specific period of time. Vickers Hardness Test is the standard method for measuring the hardness of metals, particularly those with extremely hard surfaces: the surface is subjected to a standard pressure for a standard length of time by means of a pyramid-shaped diamond. The diagonal of the resulting indention is measured under a microscope.

The procedure for testing is very similar to that of the standard Vickers hardness test, except that it is done on a microscopic scale with higher precision instruments. The surface being tested generally requires a metallographic finish; the smaller the load used, the higher the surface finish required. Precision microscopes are used to measure the indentations; these usually have a magnification of around X500 and measure to an accuracy of +0.5 micrometers. Also with the same observer differences of +0.2 micrometers can usually be resolved. It should, however, be added that considerable care and experience are necessary to obtain this accuracy.

The Knoop hardness number KHN is the ratio of the load applied to the indenter, P (kgf) to the unrecovered projected area A (mm^2),

$$KHN=F/A=P/(CL^{\wedge}2) \qquad (1)$$

Where,

F = applied load in kgf, A = the unrecovered projected area of the indentation in mm^2, L = measured length of long diagonal of indentation in mm, C = 0.07028 = Constant of indenter relating projected area of the indentation to the square of the length of the long diagonal.

The Knoop indenter is a diamond ground to pyramidal form that produces a diamond shaped indentation having approximate ratio between long and short diagonals of 7:1. The depth of indentation is about 1/30 of its length. When measuring the Knoop hardness, only the longest diagonal of the indentation is measured and this is used in the above formula with the load used to calculate KHN. Tables of these values are usually a more convenient way to look-up KHN values from the measurements.

The figure 2 shows the Vickers pyramid diamond indenter indentation. The Vickers Diamond Pyramid hardness number is the applied load (kgf) divided by the surface area of the indentation (mm^2),

$$HV = (2F \sin(136°)/2)/d^2 \quad (2)$$

$$HV = 1.854\, F/d^2 \text{ Approximately} \quad (3)$$

Where,
F= Load in kgf, d = Arithmetic mean of the two diagonals, d1 and d2 in mm, HV = Vickers hardness

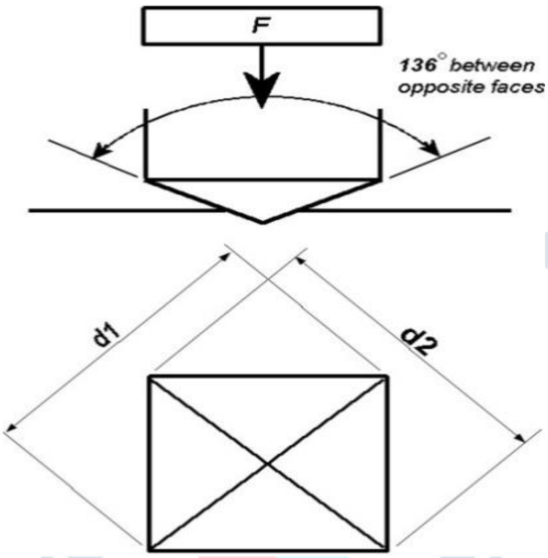

Fig.2. Vickers Pyramid Diamond Indenter Indentation

The Vickers Diamond Pyramid indenter is ground in the form of a squared pyramid with an angle of 136° between faces. The depth of indentation is about 1/7 of the diagonal length. When calculating the Vickers Diamond Pyramid hardness number, both diagonals of the indentation are measured and the mean of these values is used in the above formula with the load used to determine the value of HV. Tables of these values are usually a more convenient way to look-up HV values from the measurements.

M. A. Abdel-Rahman et al. the aim of their work was to produce a high strength 6xxx series Aluminum alloy by adjusting the processing conditions, namely solutionizing and natural aging. It consists of heating the alloy to a temperature at which the soluble constituents will form a homogeneous mass by solid diffusion, holding the mass at that temperature until diffusion takes place, then quenching the alloy rapidly to retain the homogeneous condition. In the quenched condition, heat-treated alloys are supersaturated solid solutions that are comparatively soft and workable, and unstable, depending on composition. At room temperature, the alloying constituents of some alloys tend to precipitate from the solution spontaneously, causing the metal to harden in about four days. This is called natural aging. During their work they are monitoring the effect of natural aging on the properties of positron lifetime and Vickers hardness parameters. They found that Vickers hardness of 6066 alloy has a maximum value (80) after (10) days of quenching at 530°C which is the solution temperature of this alloy and the hardness of 6063 alloy has a maximum value (40) after (14) days of quenching at 520°C which is the solution temperature of this alloy.

IV. CONCLUSION

This paper has presented an overview focusing on microstructure of Aluminum alloy. It also gives the detail about the microhardness calculation. Microstructure development during extrusion manufacturing of commercial Aluminum alloys were investigated in as-cast, as-homogenized, and as-extruded state to understand the effect of process parameters on as-extruded microstructure. Microstructure characteristics studied included the grain structure, inter-granular constituent particles and the intra-granular dispersoids. The steps to measure the microhardness is presented. Formulae for Knoop and Vickers hardness are provided to calculate the microhardness.

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