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Effect of deformation on the mechanical and physical properties of Aluminum Alloy 6061

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Aluminum alloy were subjected to multi-directional forging (MDF) and non-isothermal annealing. The forging is done on a hand operated 100,200,400 and 500 tons capacity hydraulic presses. Hardness test has been done on the Rockwell Hardness Testing Machine and check microstructure through SEM image.

Keywords: Forging, microstructure, hardness

1. INTRODUCTION

Pure aluminum when subjected to deformation shows an increase in hardness and electrical resistance and decrease in conductivity as the amount of deformation increased. Aluminum 6061 alloy processed by press forging at ambient temperature has shown that the hardness increase as the range of thickness reduction suffered increases from 0 to 20 percent while the ductility decreases an indication of a low strain-hardening exponent. Cold working of metal causes grain distortion and introduces imperfection in the crystal structure which affects the electrical property of the alloy. When cold working is combined with heat treatment, it serves the purposes of controlling final physical/mechanical properties by significantly improving structure homogeneity [1]. Physical properties such as ductility, strength and toughness are much better in a forged matrix than in the base metal due to random orientation of crystals. This accounts for preference to some level of deformation on alloys in order to achieve improved mechanical properties. A compression test determines the characteristics of materials under crushing loads. The sample is compressed and deformation at various loads is noted. Compression Tests are of extremely high importance, because it helps to calculate the different material properties that are applicable to hot as well as cold metal forging employed for different metal forming applications. It becomes important to find the suitable load to carry out the operations. Load depends on the materials and flow stress. Flow behaviour of aluminium at different strain rate can be determined by establishing a relationship between flow stress, strain and strain rate. When a compressive load is applied on a specimen, the deformation may take place: for brittle materials it may be crushing or fracture and for ductile material it may be due to elastic or plastic [2].

[3]Mohammad Reza Jandaghi et al. (2016)studied aspecimens of hot-extruded AA5056-H38 aluminum alloy were subjected to multi-directional forging (MDF) and non-isothermal annealing. The combined effects of imposed strain and post-annealing on the microstructural evolutions, mechanical properties and electrical conductivity were investigated. Optical microscopy observations showed that consecutive passes of MDF resulted in grain refinement and nonuniform strain distribution created lamellar structure right after the second pass. According to the SEM micrographs, increasing the processing strain led to severe fragmentation of initial coarse intermetallic particles into ultrafine dispersoids and redistributed them within matrix. Meanwhile, during the annealing stage, recrystallization started from stress concentrated locations while asymmetric strain distribution eventually caused bimodal microstructure. Mechanical properties were evaluated using

hardness and shear punch tests since results were in good agreement with microstructure transformations. Four-point probe electrical resistivity test outputs indicated that electrical conductivity had inverse relationship with dislocations density and grain boundaries volume.

[4]Juqiang Li et al. (2015)studied AZ61 magnesium alloy was processed using a new strategy for multidirectional forging (MDF) with an increased strain rate to obtain homogeneous and fine microstructures. The effect of the MDF process on the microstructure and mechanical properties of the alloy was investigated. It was revealed that the grain size decreases, and the homogeneity of the microstructure simultaneously increases, with the number of MDF passes. After four MDF passes, a homogeneous and fine microstructure with the average grain size of 6.1 μm was achieved. Additionally, dynamic precipitation of the Mg17Al12 phase occurred during the fifth MDF processing pass. The mechanical properties of the AZ61 alloy increased gradually as the number of passes increased from one to four passes, and the sample undergoing MDF exhibited an excellent combination of mechanical properties after the fourth pass, including the yield strength, ultimate strength and elongation to failure, which reached 241 MPa, 303 MPa and 13%, respectively. These values are 97%, 66% and 189% higher, respectively, than for the sample that did not undergo MDF. After the fifth MDF processing pass, the mechanical properties of the alloy decrease sharply, which may be attributed to the dynamic precipitation of the Mg17Al12 phase during this pass.

[5]M.G. Jiang et al(2015) studied Multi-directional impact forging (MDIF) and subsequent heat treatment were applied to an as-cast AZ61 Mg alloy and the microstructure, texture evolution and mechanical properties were systematically investigated. The microstructural evolution during MDIF was classified into twinning-active and dynamic recrystallization (DRX)-predominant stages. During the early forging passes, a complicated twinning behavior was observed, including {10–12} primary, {10–12}–{10–12} secondary and {10–12}–{10–12}–{10–12} ternary twins with various twin variants, and even detwinning behavior. With further continuous forging, {10–12} twins disappeared leading to the formation of coarse DRXed grains, and fine DRXed grains began to nucleate at serrated grain boundaries of the coarse DRXed grains due to discontinuous DRX mechanism and progressively consumed the coarse DRXed grains, eventually resulting in a bimodal microstructure. Meanwhile, as-cast random texture turned into a special non-basal texture. After subsequent heat treatment at 400 °C for 2 h, the coarse eutectic network completely disappeared with fine β-Mg17Al12 particles uniformly locating at grain boundaries and the non-basal texture stayed stable, thereby resulting in a good balance of strength (ultimate tensile strength of 259 MPa) and ductility (20.6%).

[6]Naser et al.(2014)studied the Mechanical Behaviour of Multiple-forged Al 7075Aluminium Alloy in 2014. The mechanical behaviour of any material can be described using several tests, such as, compression, tensile, hardness test, etc. In this work, cold and hot compression tests and hardness measurements were utilized. The subject material of this study was the Al 7075 alloy in the initial state (IS) and the multiple forged (MF) state. The cold compression test at room temperature was used to measure the deformation anisotropy on the MF specimen, while the hot compression test results were used as a source data in order to establish the constitutive equation in the wide ranges of working temperature (from 250 to 450°C) and strain rate (from 0.002 to 2 s-1). The homogeneity and structure of the material were evaluated using the Vickers hardness measurements and optical microscopy images. Multiple forging (MF) is one of the severe plastic deformation (SPD) techniques, which is used to refine the grain size down to nanostructure range. The principle of this technique is to perform multiple repeats of open-die forging operations,

while changing the axis of the load by 90° at each pass. The strain magnitude in one pass of multiple forging is

around 0.6; three passes of MF can push the accumulated strain to a high level. For instance, the strain magnitude during the first pass of equal channel angular press (ECAP) is around 1, and this is where the grain refinement occurs. The MF technique provides less homogeneity compared to other SPD techniques, however, it produces larger specimen dimension. The grain refinement has high effect on several material properties such as strength, fatigue and super plasticity.

[7]Purohit et al. (2012)studied a Prediction of hardness of forged Al7075/Al2O3 compositesusing factorial design of experiments in 2012. Aluminium based Metal Matrix Composites (MMCs) with aluminium matrix and non-metallic reinforcements are finding extensive applications in automotive, aerospace and defense fields because of their high strength-to- weight ratio, high stiffness, hardness, wear resistance, high-temperature resistance, etc. compared to their monolithic counterparts. They are generally manufactured by melt casting route and powder metallurgy techniques. Often, they are subjected to secondary manufacturing processes like extrusion, rolling, forging, etc. to obtain the final components. There are no standard methods for selecting the correct proportion of the constituent matrix and reinforcement materials for producing these composites, particularly, in their forged condition.

[8]Balogun et al. (2011) presented the Effect of Deformation on the Mechanical and ElectricalProperties of Aluminium-Magnesium Alloy in 2011. This paper presents the effect of deformation on the tensile strength, toughness, hardness and electrical resistance of aluminium 6063 alloy. Cast samples were cold rolled in the range of 0-24 percent thickness reduction and subjected to mechanical (static, dynamic) and electrical resistance tests. Results show significant improvement in hardness and electrical resistance properties of the alloy. The nature, amount and distribution of the secondary phase, Mg2Si, particles precipitated within the matrix which was influenced by the extent of cold-work, are responsible for the observed behaviour. The resistance of the alloy also depends on the degree of cold work carried out prior to use. Aluminium 6063 alloy processed by upset forging and cold rolling at ambient temperature has shown that the UTS and hardness increase as the range of thickness reduction suffered increases from 0 to 50 percent while the ductility decreases, an indication of a low strain-hardening exponent . Cold working of metal causes grain distortion and introduces imperfection in the crystal structure which affects the electrical property of the alloy.

2.0 EXPERIMENTAL APPROACH

2.1 Material Selection Process

Aluminum 6061 alloy is taken as work piece after the study of a lots of paper. Aluminum alloy 6061 is a medium strength alloy commonly referred to as an architectural alloy. It is normally used in intricate extrusions. It has good surface finish, high corrosion resistance, is readily suited to welding a can be easily anodized. Aluminum alloy find extensive uses in engineering applications due to its high specific strength. These alloys are basically used in applications requiring lightweight materials, such as aerospace and automobiles. The 6XXX- group alloy have a widespread application, especially in the building, aircraft and automotive industry due to their excellent properties. The 6XXX series contains Si and Mg as main alloying elements. These alloying elements are partly dissolved in a primary α-Al matrix, and partly present in the form of intermetallic phases. A range of different intermetallic phases may form during solidification, depending on alloy composition and solidification condition. Relative volume fraction, chemical composition, and morphology of structural constituents exert significant influence on their useful properties.

2.2 MATERIAL COMPOSITION AND SPECIFICATIONS

First of all, six pieces were cut with the help of hacksaw of dimension (120 × 100 ×12) mm each and then tests were performed. The composition was tested in Batra metallurgical and spectro station, New Delhi.

Fig.2.1 Original Specimen

Table 2.1 Composition of Material.

Element	% Weight
Si	0.41
Fe	0.68
Cu	0.16
Mn	0.21
Mg	0.81
Zn	0.22
Ni	0.01
Pb	0.047
Al	97.45

2.3 SAMPLE PREPARATION

2.3.1 Forging

Frist of all the aluminum alloy 6061 plate is cutted into five pieces of dimension 120mm*100mm*12.5mm and the edges is finished with the help of filler. Thickness of plate is measured with screw gauges.

2.3.2 Microstructure

After forging a piece of dimension (1 inch *1 inch) is cutted from each plate with help of hacksaw. And the work piece is finished with different grades (100, 220, 300, 500, 800, 1000, 1200, 1500 and 2000) emery papers. One face of work piece is to be highly finished for further finishing polishing is performed with the help of vibro meter. Then etching is to remove oxide from surface so that the grain boundaries will be clear visible.

2.3.3 Polishing

The VibroMet2 Vibratory Polisher removes minor deformation remaining after mechanical preparation revealing a stress-free surface without need for the hazardous electrolytes required by electro-polishers. Combine the VibroMet 2 with MasterMet 2 collidal silica to chemo-mechanically polish a specimen to a surface finish suitable for electron-backscatter diffraction (EBSD) or atomic force microscopy (AFM). Unlike traditional vibratory polishers, the VibroMet 2 oscillates almost entirely horizontally, maximizing the length of time the specimen touches the polishing cloth. Specimens naturally rotate around the polishing bowl allowing users to set-up the system and walk away.

The Circular Vibrator Polishing Machines are mass finishing machines, used for deburring, polishing, descaling, and surface treatment of metal and plastic components, Vibratory tumble finishing systems produce a cutting action, shaking the processing vessel (finishing tub) at a high speed thus causing the tumbling media and parts to scrub against each other. These scrubbing actions remove burrs. Rotating in eccentric motion weights mounted on the tub produces the shaking action, these deburring machines and finishing systems produce a cutting action that is very thorough and remove material from pockets and recesses and inside bores unlike barrel tumbler, so are used for delicate or intricate parts. With high speeds and a short stroke, also run large bulky parts without damage such as large wing spans. The action is that of a small orbit at a high speed and thus is very powerful and causes little stress on the parts.

2.3.4: Etching

The freshly prepared mixture of 10 parts nitric acid, 1 part hydrofluoric acid, and balance distilled water (known as Keller's reagent) are used. Use a cotton swab or Q-tip to develop the grain structure on the surface of a highly polished specimen. Use a new swab each time to apply etchant for about 10 seconds only. Rinse and dry to examine. Repeat as necessary. You will develop improved technique with experience. Aluminum alloys will respond vastly different from relatively unalloyed aluminum, also

2.3 HYDRAULLIC PRESS

The forging is done on a hand operated 100,200,400 and 500 tons capacity hydraulic presses. A hydraulic press is a device using a hydraulic cylinder to generate a compressive force. The hydraulic press depends on Pascal's principle: the pressure throughout a closed system is constant. One part of the system is a piston acting as a pump, with modest mechanical force acting on a small cross-sectional area; the other part is a piston with a larger area which generates a correspondingly large mechanical force.

Fig.2.2 Hydraulic Press

A fluid, such as oil, is displaced when either piston is pushed inward. Since the fluid is incompressible, the volume that the small piston displaces is equal to the volume displaced by the large piston. This causes a difference in the length of displacement, which is proportional to the ratio of areas of the heads of the pistons given that volume = area×length. Therefore, the small piston must be moved a large distance to get the large piston to move significantly. Thedistance the large piston will move is the distance that the small piston is moved divided by the ratio of the areas of the heads of the pistons. This is how energy, in the form of work in this case, is conserved and the Law of Conservation of Energy is satisfied. Work is force applied over a distance, and since the force is increased on the larger piston, the distance the force is applied over must be decreased [9].

2.4 ROCKWELL HARDNESS TESTING

Hardness test has been done on the Rockwell Hardness Testing Machine at government engineering college Banda**.** Hardness is defined as resistance to local penetration, scratching, machining, wear or abrasion, and yielding. In the Rockwell method of hardness testing, the depth of penetration of an indenter under certain arbitrary test conditions is determined. The indenter may either be a steel ball of some specified diameter or a spherical diamond-tipped cone of 120° angle and 0.2 mm tip radius, called Brale.

In order to get a reliable reading the thickness of the test-piece should be at least 10 times the depth of the indentation. Also, readings should be taken from a flat perpendicular surface, because convex surfaces give lower readings. A correction factor can be used if the hardness of a convex surface is to be measured.

Fig.2.3 Rockwell Hardness Testing Machine

2.4.1 PROCEDURE

- Ensure that lever of the machine is in unload position and large niddle should be on set position.
- Place the specimen on the platform and adjust with the help of rotating wheel till small pointer matches red spot.
- Now turn the lever to load position and wait till large niddle get stable.
- Now again turn the lever to unload position.
- Get the final reading of the large niddle which is in HRB.

3.0 RESULTS AND DISCUSSION

For different specimens the percentage reductions in thickness (in percentage) afterthe application of load are given below.

3.1 forging

Table 3.1 Load and Thickness Variation

Steps	1	2	3	4	5
Load Applied In Tons	0	100	200	400	500
Thickness Reduction In %	0	6	9.8	15.6	20
Specimen Thickness In Mm	0	11.52	10.8	10.13	9.6

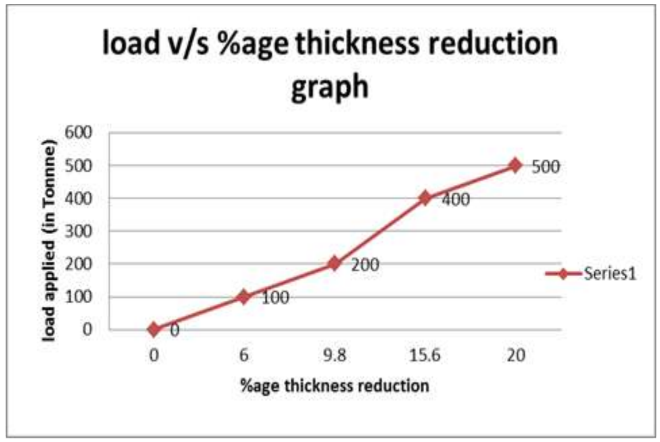


Fig 3.1 Load V/S Percentage Reduction in Thickness

Description: when 100 tons load is applied on work piece then the reduction in work piece will be 6% .And when 200 tons is applied on second work piece then reduction in that work piece is 9.8%. When 400 tons load is applied on work piece then the reduction in work piece is 15.6% and when 500 tons is applied then reduction in thickness of work piece is 20%. We see from the graph that as load increases the %age reduction also increases gradually.

3.2 HARDNESS

The hardness values of original and compressed specimens are given in the table. The hardness value is obtained on scale B and hardness values are in HRB.

Table 3.2 Hardness Value of Specimens

S.No.	1	2	3	4	5
%THICKNESS REDUCTION	0	06	9.8	15.6	20
HARDNESS (IN HRB)	63-64	66-67	68-69	75-76	77-78

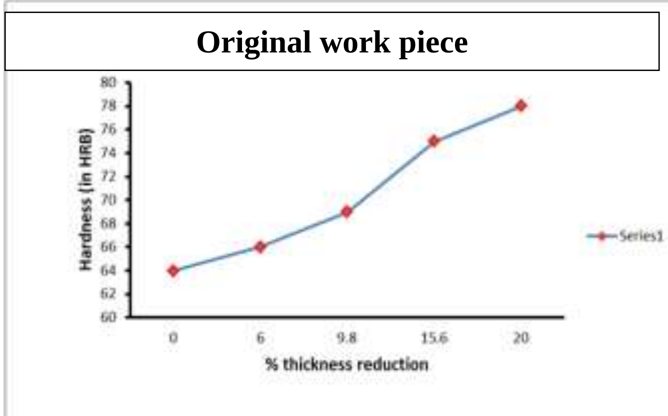
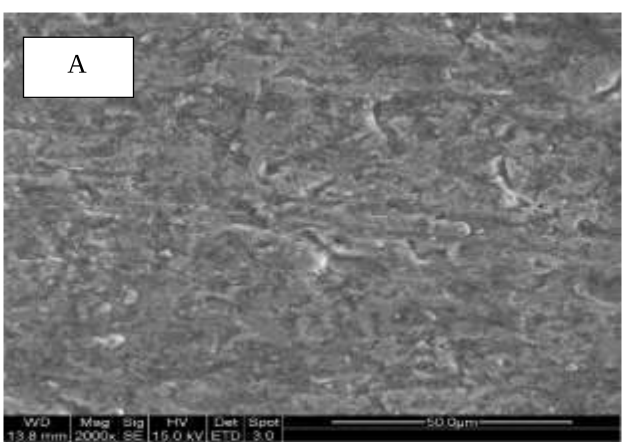
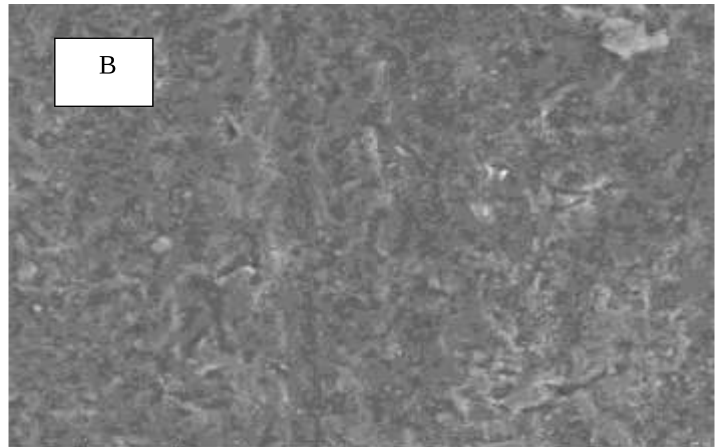


Fig. 3.2 hardness vs. percentage thickness reduction

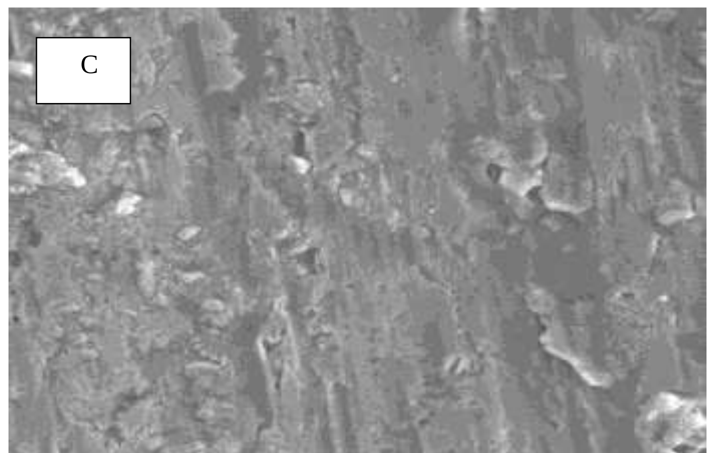
DESCRIPTION: The hardness of test samples increases nearly linearly within 0-20 percent thickness reductions whereas there is no significant increase in hardness between 6 and 9.8 percent thickness reduction. At 9.8 percent and beyond, hardness values increase gradually to the maximum, 78 HRB, at 20 percent reduction. The reason for this is that at 0-20 percent reduction, there seems to be temporary saturation in the generation of immobile dislocations as a result of reduction in the amount of Si precipitates produced. Micro-hardness (y) of the forged composites was expressed as a function of reinforcement size(D), % weight of reinforcement (W), forging temperature (Tf) and reduction in area (Rf), The response is a function of all the process variables and is given as **y = f(D, W, Tf, Rf).**

3.3 MICROSTRUCTURE.

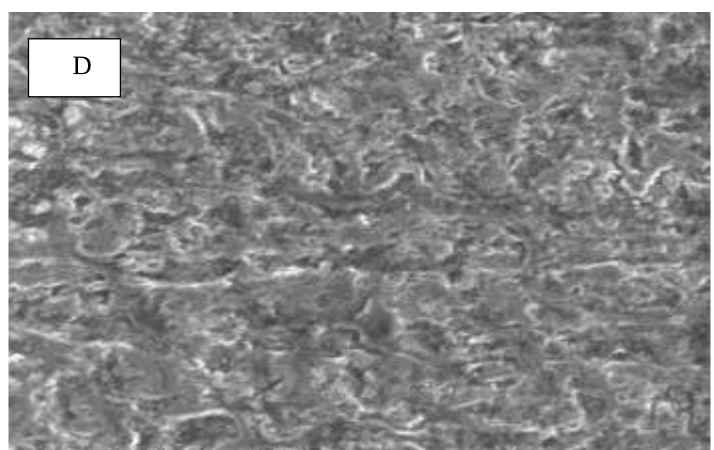




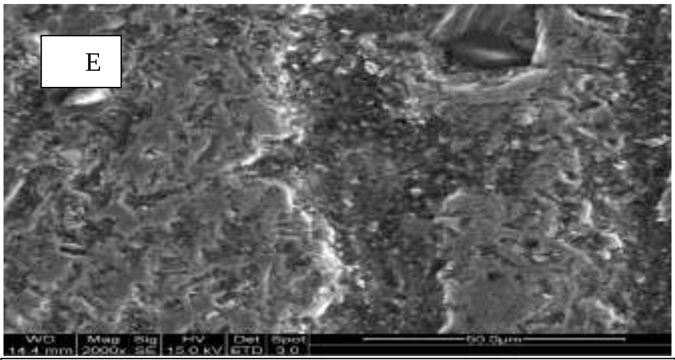
After 100 tons load applied



After 200 Ton load applied



After 400 Ton load applied



After 500 Ton load applied

Fig 3.3 SEM Images

- **In figure A** - Black dots are showing cluster of FeMnSiAl. Cluster of foreign element (like Fe, Si, Cu, Mn, Mg, Pb, Zn) is formed in between the Al particles. And at some places the white spots are showing the presence of Zn and Mg.
- **In figure B -** Precipitation of Mg and Zn are shown by bright white crystals. Acicular compounds (Al and Cu) are shown by a narrow white line. As the load applied is increased, these clusters get deformed in small particles.
- **In figure C -** As there is increase in the forging load temperature of work piece also increases hence new grains are generated, due to which the hardness of aluminum alloy 6061 will be increased continuously. Precipitation of Mg and Zn is large as the load increases and formed the bigger grain.
- **In figure D -** Process of diffusion occurs along the grain boundaries, along the surface of solid at 400 tons load. There are twins formation that takes place due to edge dislocations and they are similar to needle shape.
- **In figure E –** The presence of fine Mg_3Zn and $CuAl_2$ phases precipitated within the grains are clearly seen. Due to increase in the forging load the homogeneity of structure also increases.

4.0 CONCLUSIONS

Aluminum when subjected to deformation shows an increase in hardness and decrease in conductivity as the amount of deformation increased. Aluminum 6061 alloy processed by press forging at ambient temperature has shown that the hardness increases as the range of thickness reduction suffered increases from 0 to 20 percent.

The following points are concluded from this project:

- It has been shown that hardness increases from 0 to 20 percent thickness. It is due tothe fact that there seems to be temporary saturation in the generation of immobile dislocations as a result of reduction in the amount of Si precipitates produced. As we know that hardness increases with increase in saturation of particles. So there is increase in graph as shown.
- There is increase in homogeneity of solution as it becomes more isotropic due to precipitated Mg2Si crystal are absorbed in the matrix. Due to absorption of particles in matrix there is an increase in the visible layers of the grain boundary. So we can see increase in thin and visible grain boundaries.

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