Modelling and Simulation of The Grain Deformation During Extrusion of Aluminium Casting Alloy (LM6) By Finite Element Method

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Abstract— **In any metal forming process, there’s a high values of stresses and friction forces will generates due to sever interference between the contact surfaces. Extrusion process of aluminium casting alloy (LM6) is an obvious example for this case. Investigate the behavior of internal dislocation during the process is the main key to control the parameters which effects on the process efficiency. During this analysis; it’s assumed that, the effects of some of extrusion conditions on the grain size distribution after extrusion like (ram speed and extrusion temperature) will be neglected. Microstructure changes of aluminium casting alloy (LM6) are used to study by a combination of numerical analysis using finite element technique and experimental process. The commercial code (ABAQUS/ CAE) software was adopted for analysis and simulation the thermo-mechanical behavior of the grain size and microstructure during this process, and investigates conditions on grain thickness distribution after the of extrusion. Scanning Electron Microscopy (SEM) used to show the microstructure before and after extrusion. Finite Element results reveals that; the homogeneous of the extruded shape is depend on the condition of the as – cast billet as well as the initial billet temperature. It was found through simulation process that the grain size is small in the center of the deformed extrudate and this size will increase gradually near the surface. Also, it’s observed from the microstructures test that there is a transition in all Non-Recrystallized extrudates particles at the center is different from those at the surface. As a conclusion, it’s found that there is a high effect for temperature and extrusion ratio on grain size and their distribution.**

Keywords— Extrusion, Aluminium alloys, Microstructure, Finite Element Method, ABAQUS.

I. INTRODUCTION

Nowadays; one of the important methods of manufacturing and forming process for various metals are the extrusion method. Aluminium casting alloy (LM6) is widely used in many industrial applications due to the excellent mechanical and physical properties like durability, hardness, and extrudability. During extrusion process, the grain size will subject to change in their shape and distribution due to high deformation which leads to grow a new grain size. This change in grain size can affect the mechanical properties of the extruded parts [1, 2]. It’s found from many previous researches that; the understanding of microstructural evolution, hot workability and effect of micro-alloying elements during extrusion process are the main key for optimizing the mechanical properties of (LM6). Mechanical processing are highly effected by microstructure, strain history (the strain paths) and chemical composition. In high elevated temperature, and during the forming process; dynamic recrystallization is happened normally. Many aluminium alloy exhibit high stacking during deformation with significant dynamic recrystallization especially in high temperature values [3, 4, 5]. Aluminium casting alloy (LM6), is an alloy of (11.8) % silicon eutectic alloy, and according to the diagram of aluminium-silicon binary alloy phase; the (LM6) alloy melting point is (575) °C, and this temperature usually called a eutectic temperature. Also this eutectic phase normally solidification at a constant temperature [6].

During hot deformation of aluminium billet, and due to high stacking fault energy; dynamic recovery is the dominant softening mechanism in many of aluminium alloys and leads to new grain formation [7, 8]. However; this change in grain size will remain in a steady state plastic stain and can withstand high pressure values due the new recrystallization form [9]. When the values of strain become very high, the grain size thickness will decrease, and original grain will pinch-off like as it separate and form a new grains, and then each sub grain will be a new grain. This sub grain formation will leads with a fine grain size gain and finally give a high enhancement and improvement to the mechanical properties [10, 12]. The formation of new small grain is normally occurs in hot forming process, and especially in hot extrusion of aluminium alloys. This formation is like a phenomenon and many researchers called it as geometric dynamic recrystallization [13, 14].

II. MAIN OBJECTIVES

The main objective of this study is to explore the extrudability of aluminum casting alloy (LM6) theoretically

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through the simulation process of metal deformation, and experimentally by microstructure test. This analysis will give a high indication about the behavior of the metal grain during deformation, which can help to avoid many errors in experimental part. Modeling and analysis this type of manufacturing process will help to expand the knowledge and gives more understanding on this field.

III. Part geometry and Materail Properties

The (LM6) raw material of (as cast) is basically available as a rounded bar, and by machining process is prepared to the dimensions (Ø 50 * 100) mm , as shown in Fig. 1.

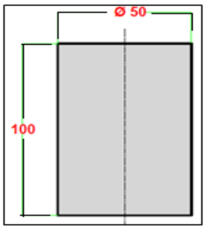


Fig. 1. Dimensions of Raw Material.

The mechanical properties of (LM6) are listed in Table I.

TABLE I. MECHANICAL PROPERTIES OF (LM6).

No	Property	Values
1	0.2% Proof Stress (N/mm^2)	60-70
2	Tensile Stress (N/mm^2)	160-190
3	Elongation (%)	5-10
4	Impact Resistance. Izod (Nm)	6.0
5	Brinell Hardness	50-55
6	Endurance Limit N/mm^2	51
7	Modulus Of Elasticity N/mm^2	71 71
8	Shear Strength N/mm^2	120

IV. Tools Design and Simulation Process

The main procedure and methodology which used to show the results and complete this research was done through many steps including mould and tools design by AutoCAD. modelling and simulation by (CATIA) and (ABAQUS) software. These steps are illustrated in Fig. 2.

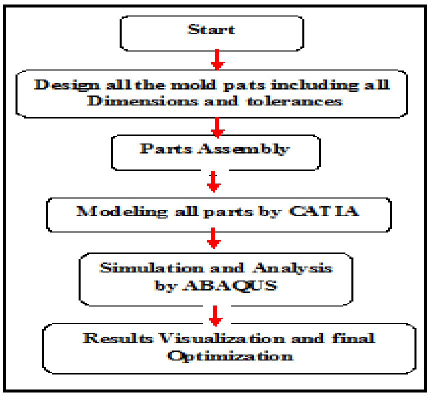


Fig. 2. Flowchart Explains the Analysis Steps.

The completed tools which used in this extrusion process are consisting of many parts, like die, punch, billet container, centering guides, and other support parts. A suitable hydraulic press associated with ejection system is used to press the aluminium billet inside the billet container by using a located punch. All parts should be in fit alignment by using cantering guides to avoid any parts distortion. The material of the effective parts in this assembly should be used as high grade steel with high hardness and fabricated as a portable inserts in order to change it whenever required. Fig. 3 illustrates the completed mould assembly.

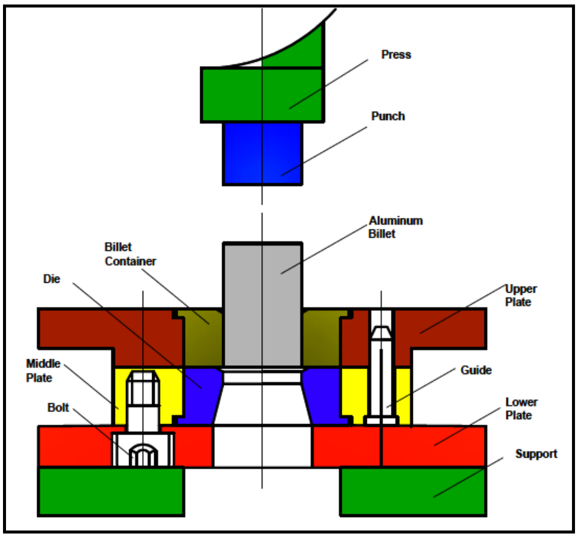


Fig. 3. Completed Mould Assembly.

Modelling all the tool parts including the assembly is an important step to avoid any error or conflict before the fabrication and experimental test. CATIA software was adopted for this step. These steps are shown in Fig. 4, Fig. 5.

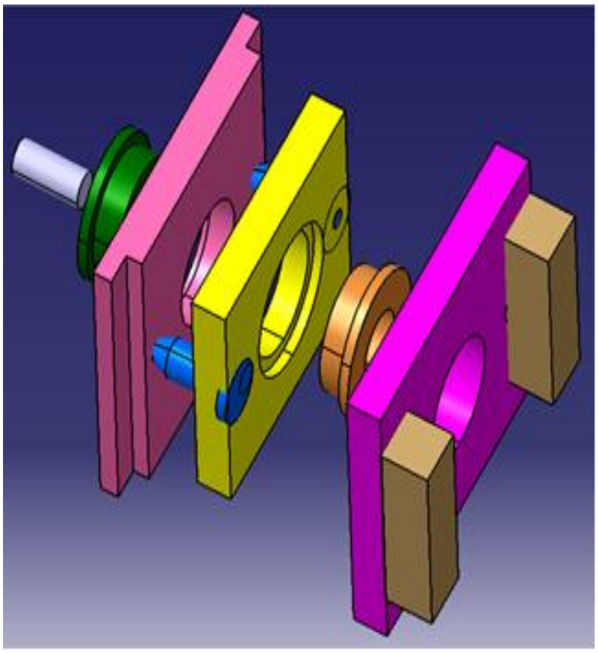


Fig. 4. 3D Modelling for Assembly Tools.

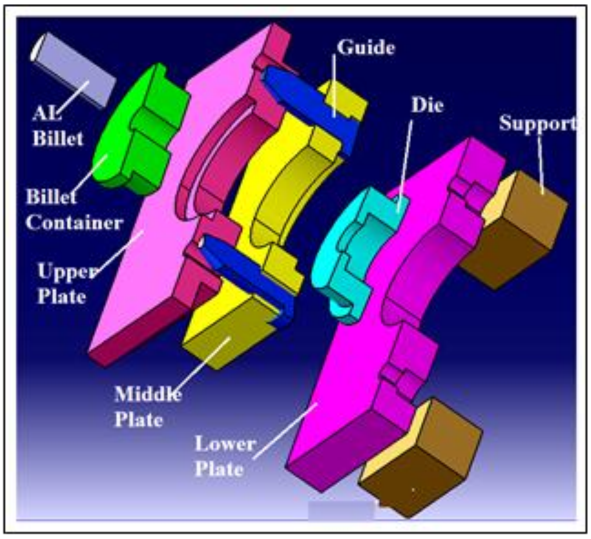


Fig. 5. Cross Sectional View of the Mould in 3D Form.

The commercial software of finite element package (ABAQUS /CAE) was adopted for simulation and analysis step for this process. The Lagrangian procedure is widely used for analysis in this software. In this research, the model consists of four effective parts which are; punch, die, billet container, and the billet. In this forming process simulation; there are a lot of plastic deformation will generated during billet compression, so the billet will consider as a deformable body, while the die and punch will define as rigid body. The system are modelled as two dimensional Quadrilateral element type, axis symmetric, isoperimetric, Quadrilateral element, and set up to four node series as shown in Fig. 6.

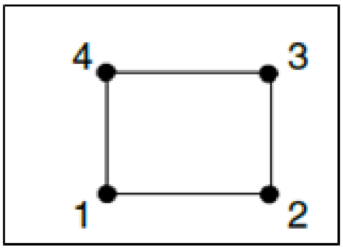


Fig. 6. Quadrilateral Element Type.

In simulation process, the deformation was represented as anodal displacement for the billet. Nodal movement during grain dislocation under pressure will gain these nodal a high energy which causes separation of grain to a sub grain as shown in Fig. 7.

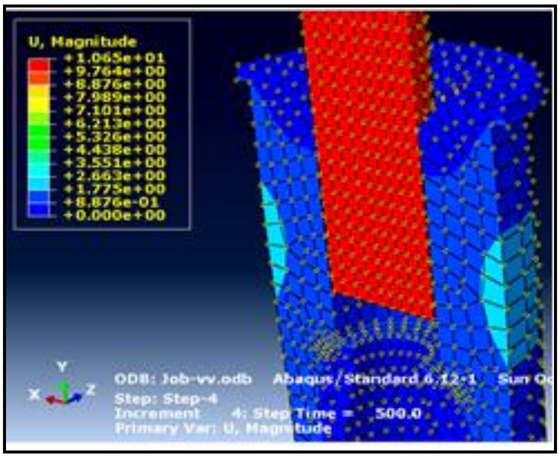


Fig. 7. Nodal Displacement During Extrusion Process.

Modified upper bound equation is used to calculate the extrusion force F [15].

$$F = 2k_f * [4\mu * (H / D + h / d) + \mu / (\sin\alpha + 1) * \ln(D^2/d^2)] \qquad (1)$$

Where (H) and (h) are the billet height and die land height in (mm) respectively. (D) and (d) are the billet and die land diameter in (mm) respectively. (k_f) is the maximum tangential stress at die/billet interface (N mm^{-2}), (α) is the die half angle in (°), and (μ) is the coefficient of friction at die/billet interface.

In the present work a sequential solution was done by Eulerian formulation which based on operator splitting. Two steps Eulerian conservation equations used here:-

$$\begin{aligned} &\partial\rho/\partial t + \nabla*(\rho v) = 0 \\ &\rho(\partial v/\partial t) + \rho v*(\nabla*v) = \nabla*\sigma + \rho g \qquad (2) \\ &\varepsilon = D* \nabla *h + \rho \end{aligned}$$

Where: $D = 0.5 [\nabla * v + (\nabla v) *c$ is the rate of deformation tensor. v and ρ are the velocity and density respectively. σ and ε are the Cauchy stress and the strain rate tensor respectively. For accounting the non-linear behaviour of the billet material and the material hardening; Von-Mises criterion are used for this purpose.

IV. EXPERIMENTAL PROCESS

The experimental process of extrusion process was implemented by using many rounded billet of aluminium casting alloy (LM6), which was casted and rounded to final diameter (50) mm. The billets dimension is (Ø50 x 100 Length) mm, and each one weighs approximately 390 grams. The weight of casting billet is calculated by multiplying the LM6 casting alloy density with the volume of the billet.

Density = (Mass / Volume); Mass = density x volume

Density of LM6 alloy (Aluminium-11.8% silicon alloy)
= 2.65 gms / cm^3

Main chemical compositions of LM6 are shown in Table II.

TABLE II. MAIN CHEMICAL COMPOSITIONS OF LM6.

Al	Si	Mg	Mn	Le.	Cu	Ni	Zn	Fe	Ti
86	12	0.3	0.5	0.1	0.1	0.1	0.1	0.6	0.2

For homogenizing, the billets are heat treated in (H6) condition for different times and different temperatures before the extrusion process, as shown in Fig. 8.

Fig. 8. Homogenizing Aluminum Billet in a Furnace.

The Extrusion temperature was (500) °C, and the extrusion ratio starts with a (4:1), which means the final product will be (12.5) mm in diameter, and the extrusion speed was (5) mm/ sec. Extrusion tools fabricated and assembled according to the standard as shown in Fig. 9. A lot of changes will happened during this process, especially in microstructures depending on the heating time which the material will spends in overheating temperature in the furnace.

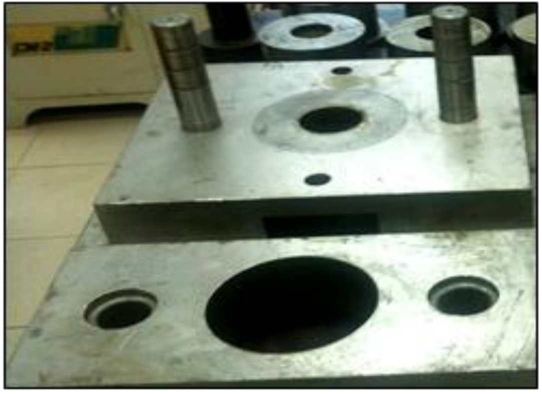


Fig . 9. Extrusion Tools after Fabrication.

The samples for optical metallography test were taken from different locations of the billet, like middle, and outer surface and prepared for (SEM) test according to the standard procedure as in Fig. 10.

Fig . 10. Aluminium Samples Prepared for (SEM) Test.

V. RESULTS AND DISCUSSION

Simulation results show that the maximum stresses (Mises stresses) in extrusion process will consternate on the external surface of the extruded billet which in touch with internal surfaces of the die and billet container as shown in the stresses contour below in Fig. 11.

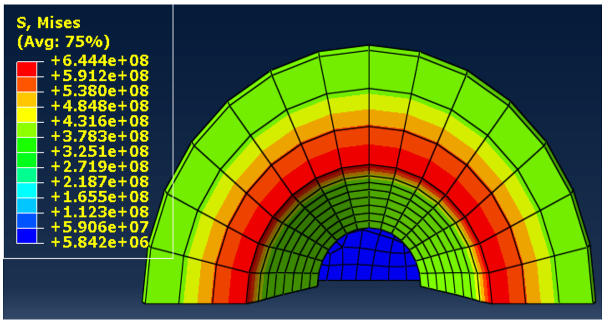


Fig. 11. Mises Stresses Contour.

One of the important results from this simulation; is that, the plastic strain was in peak value near the outside extruded billet surfaces, which due to high friction forces between the contact surfaces. The plastic strain contour in Fig. 12. show these results.

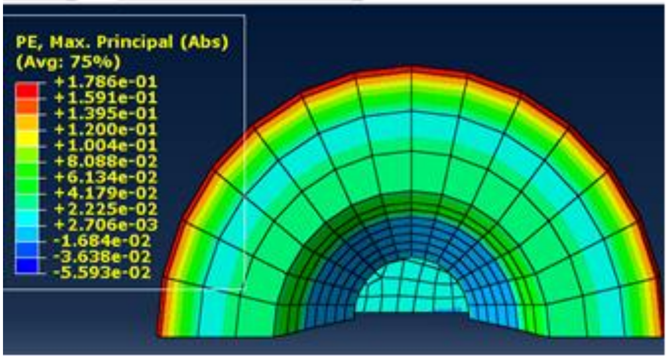


Fig. 12. Plastic Strain Contour.

The results also reveal that the principle stress concentration will be in the tool centre. These types of stresses are normally generated due to the high pressure difference inside the billet container, as show in Fig 13.

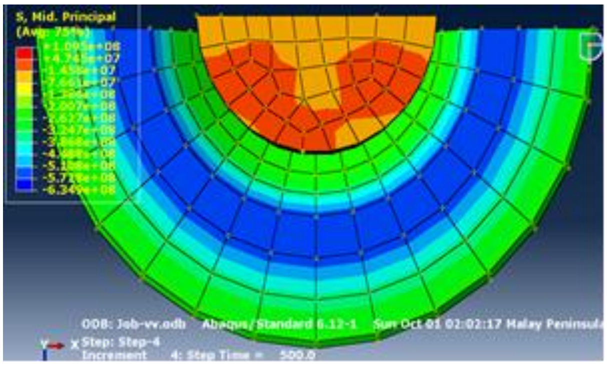


Fig 13. Principle Stress Concentration.

Experimentally; the scanning electron microscopy (SEM) test was done for many extruded samples and from different positions, like core and near the surface. This test shows that there is a transition structure from fabric to granular, with fine grain near the surface as shown in Fig. 14.a, and Fig. 14.b.

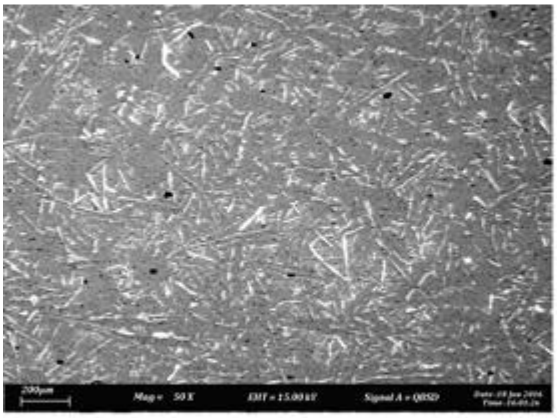


Fig. 14.a. (LM6) Micrograph Test Before Extrusion.

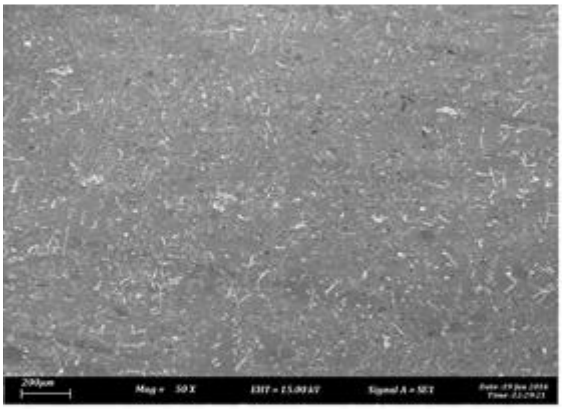
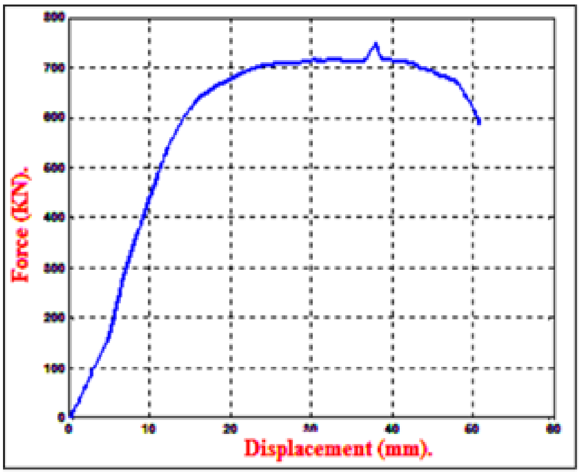


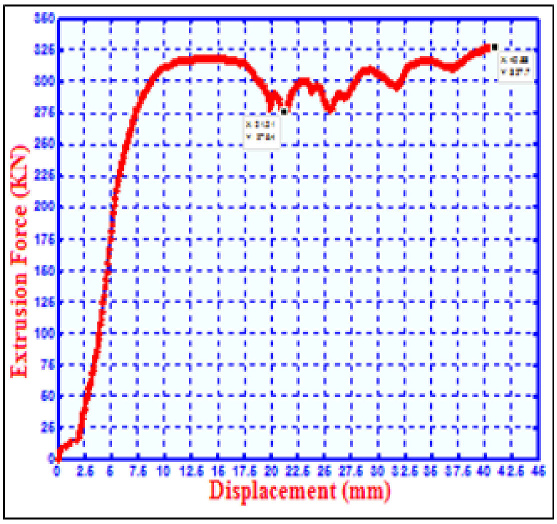
Fig. 14.b. (LM6) Micrograph Test after Extrusion.

The fine grain will form due to high interference between the particles during the dislocation which leads to occurrence of sub grain size. However, this can normally investigated during FEM process simulation according to the basic strain and temperature history data of the model in simulation process. There is a lot of difference in the force values between the hot and cold extrusion. The cold extrusion requires a high force, especially in the beginning to overcome the high resistance in the bearing area as shown in Fig, 15.



Fig, 15. Force- Displacement Graph during Cold Extrusion.

While in the case of hot extrusion, the bonding forces between the grain is weak, so the extrusion can achieved by applied small amount force, as shown in Fig. 16.



Fig, 16. Force- Displacement Graph during Hot Extrusion.

In the beginning of deformation process; there's a high resistance force due to the friction between contact surfaces, so the axial strain is very small, and this strain will proportional with force increase, as shown in Fig. 17.

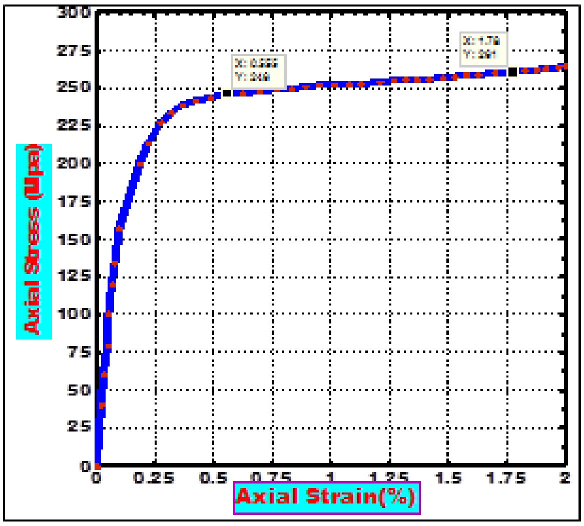


Fig. 17. Stress -strain relationship.

The Comparison between the simulation and experimental results showed some variation, especially after the yield point as shown in Fig. 18. This variation due to the elements meshes type and some differences in boundary conditions.

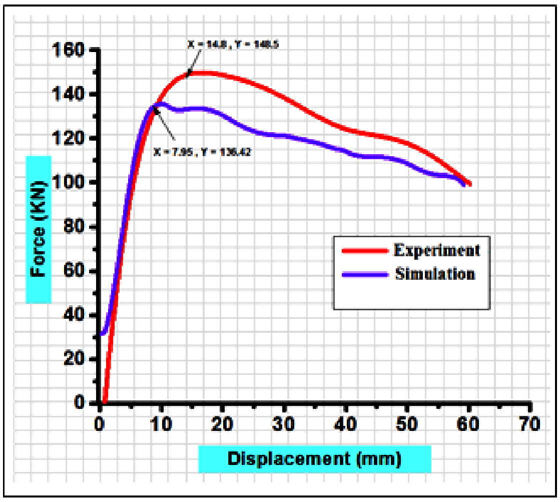


Fig. 18. Comparison between the simulation and experimental results.

VI. CONCLUSIONS

Some conclusions are raised up in this research, and can be summarized as below:-

- The extrudability of aluminium casting alloy (LM6) is depends on the condition of the as – cast billet. The initial billet temperature and porosity percentage are the main parameters which effects on this case.
- Formation of sub grain will enhance the mechanical properties due the new strong bonding between these grains.
- The friction forces between the contact surfaces are very high due to sever interference between the billet particles and the tools, and this will leads to high percentage of plastic strain.
- According to the data input information's, and the material specifications during simulation process; it's found that the nodal displacement (deformation) are depends on the hardness of extrusion tools.

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