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EFFECT OF DIE ANGLE AND FRICTION COEFFICIENT ON TEMPERATURE AND STRESS DISTRIBUTION IN THE EXTRUSION PROCESS

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Abstract: *:* Extrusion, among other types, is one of the most important forming processes due to its high productivity, lower cost and its good ability to improve the physical and mechanical properties of extruded materials. *FE simulation was carried out on ABAQUS software ver.6.9. to study the distribution of stress and temperature which created through the extrusion process. The results of present study are accentuated that, there is a complicated relationship between stress and temperature distribution relative to die angle and friction coefficient. It was found, in the range of tested cases, at friction coefficient of more than (0.08), for (45^{o}) die angle, the maximum value of temperature is twice higher than that of (75^{o}), hence the die angle has more significant effect on state of stress and temperature than that of friction coefficient. Nevertheless, a high die angle ($\alpha = 75^{o}$) emerged low value of maximum temperature due to easily flow of material toward the die orifice. Furthermore, there are a gradual increasing of vonMises criterion and temperature with increasing the friction coefficient while they are decreasing with increasing the die angle.*

Keywords: *stress and temperature distribution, die angle, friction coefficient, deformation.*

INTRODUCTION

Aluminum and its alloys are extensively used in different forming process to produce long, strong pieces of formed metal from one solid piece. As well as extrusion of aluminum alloys offers a relatively cheap method of producing complex shapes with high geometric tolerance [1]. Tiernam P. et al. [2] used finite element analysis to evaluate the influence of reduction ratio, die land height and die angle on the extraction force during cold extrusion of high grade (AA 1100) aluminum. They presented, the largest extrusion force obtained when the die angle, die exit diameter and die land are (15^{o}, 5mm, 4mm) respectively. Evan W. Albert et al. [3] studied direct extrusion of aluminum wire by FE analysis to mitigate manufacturing defects. They concluded,the increasing the ram velocity leads to decrease both of turbulence and stress irregularities because of time decreasing in which the die surface and billet are in contact.

By using port hole die method, the effect of convex die angle that would optimize the strength and a load of hot extrusion process of (A 16061) alloy of aluminum tube, have been investigated by Sangamesh Sirsgi et al. [4]. The authors were reported, with the numerical analysis of the process, the maximum stress is created on the corners of square tube. Also, finite element simulation employed to study the distribution of strain, temperature and effective stress of direct extrusion of titanium alloy [5]. They investigated the influence of different design and process parameters on maximum ram speed, applied pressure and strain and stress distribution. Adeosun S. O. [6] studied mechanical properties response of extruded aluminum (6063) alloy by using plain carbon and tool steel dies at different die entry angles. They employed finite element analysis to investigate the effect of die angle on maximum extrusion pressure and hardness of extrudate. They reported that, by taken into account the cost of manufacturing process, plain carbon steel can successfully replace tool steel as a die material without losing the desirable products. And the maximum extrusion pressure and the hardness of extruded parts are increased as the die entry angle increased. Tool steel and mild steel dies used to study the extrusion characteristic of cold, hot and annealed billets of wrought aluminum alloy [1]. Die angles ranging from (15^o to 90^o) adopted to measure the extrusion pressure, linear strain, extrusion ratio and surface hardness of extrusion products. The authors concluded, cold extrusion was easier at high die angles than that at lower die angles and the highest linear strain was obtained for cold extrusion billets by using tool steel die with (90^o) die angle. Also, the results revealed that the tool steel dies achieved superior extrusion response relative to die which made of mild steel.Rafid Jabbar Mohammed [7] utilized commercial finite element code Deform – 3D to investigat the type of metal flow and stress distribution of (Al – 1100) rod extrusion.The author reported, the finite element model was successfully simulating the stress distribution in direct rod extrusion. He found, the optimum die angle reduces the magnitude of normal, shear and effective stresses.

In this present study, FEM was employed to investigate the distribution of stress and temperature which created during direct extrusion of commercial aluminum for different values of die angle and friction coefficient. Finite element simulation was carried out on ABAQUS software V. 6.9 [8].

1. MATERIALS AND FINITE ELEMENT MODEL

The billet materials is aluminum alloy which its mechanical and thermal properties are listed in Table (1) [9]. Figure (1) indicates the FE model of the extrusion process. The analysis is adopted on consideration of coupled temperature displacement condition. The diameter and the length of the billet are (D_o = 60 mm, L_o = 180 mm) respectively. The billet goes through a die with an opening diameter of (D_i = 40 mm), it means, the extrusion ratio is (2.25, where extrusion ratio = D_o^2 / D_i^2).Three values of die angle ($\alpha = 45^o$, 60^o and 75^o) and ten values of friction coefficient (μ) from (0.01 to 0.1; with 0.01 for each step) are used to study their effect on stress and temperature distribution which generated during the extrusion process.

The use of computing software in the simulations of metal forming process, such as extrusion, rolling and drawing, is the most logical approach to achieve the reducing of unnecessary consumption of resources as time, energy and scrap material [3]. FE simulation of this study was carried out on ABAQUS V.6.9. CAX4T elements are used to mesh the billet which is considered as deformable part while the container defined as rigid surfaces. CAX4T is a 4 - nodes axisymmetric thermally coupled quadrilateral, and 2D meshes of both billet and container are created [5,8,10].The extrusion process is displacement controlled so that corresponding displacement is applied on the top of the billet.

Table 1: Mechanical and thermal properties of Aluminum billet [9]

properties	The values
Density	2700 Kg / m^3
Young's Modulus	69 x 10^3 MPa
Poisson's ratio	0.33
Conductivity	204 at 0^oC w /m.k 225 at 300 ^oC w /m.k
Inelastic heat fraction	0.9
Specific heat	880 J/ kg k
Expansion coefficient	8.42 x 10^{-5} 1/k

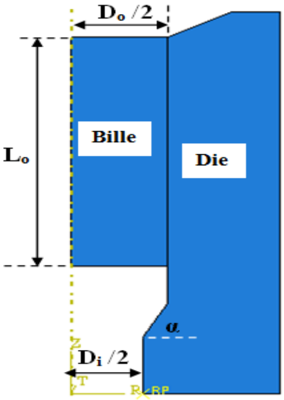

Figure 1 : Dimension of Finite Element Simulation model

2. RESULTS AND DISCUSSION

2.1. STRESS DISTRIBUTION

Figure (2) illustrates the location of maximum vonMises stress (S_{VM}) at a different stage of extrusion process at friction coefficient equal (μ = 0.05) and die angle (α = 60°). It is clear that when the billet reaches the first bend in the container, the value of maximum vonMises stress is small (131.9 MPa) because (at this region) the billet material starts deforming plastically. Then it increases gradually throughout the flow of the billet's material to the die outlet. The maximum value of vonMises stress (251.1 MPa) occurs at the end of extrusion stage when the extrusion products go out of the die orifice. A similar trend was found with different values of friction coefficient and die angle, and also with the distribution of shear stress (S_{12}) as shown in figures (3).

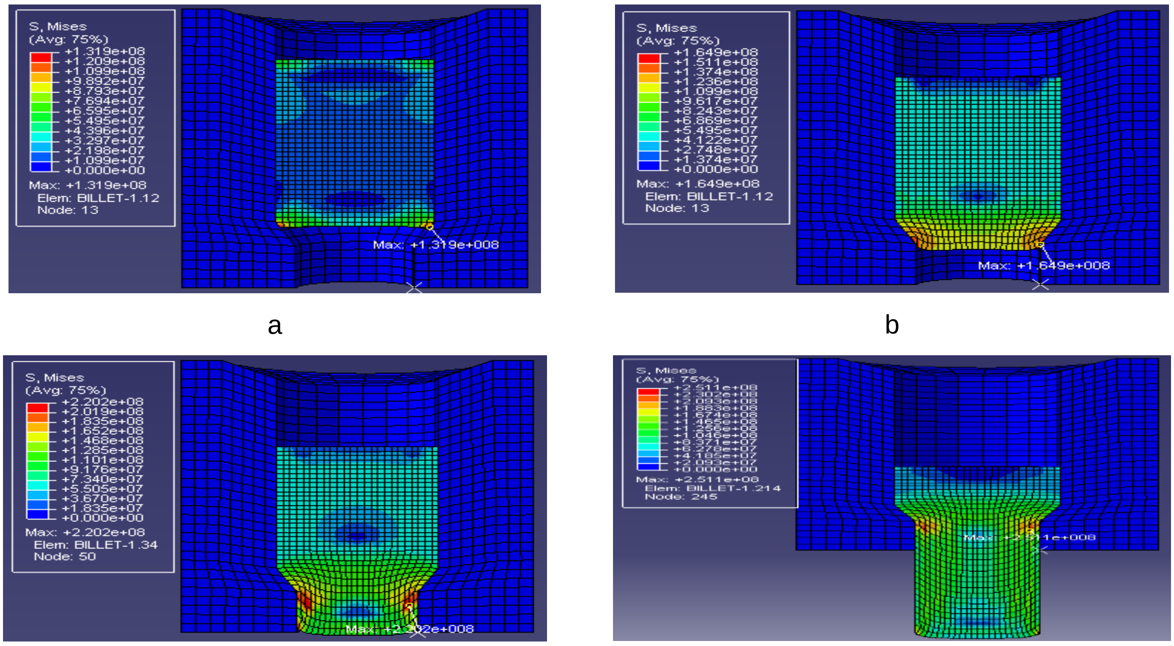

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Figure 2: Location of maximum vonMises stresses (S_{VM}) at different stage of extrusion process for friction coefficient, μ = 0.05 and die angle = 60°.

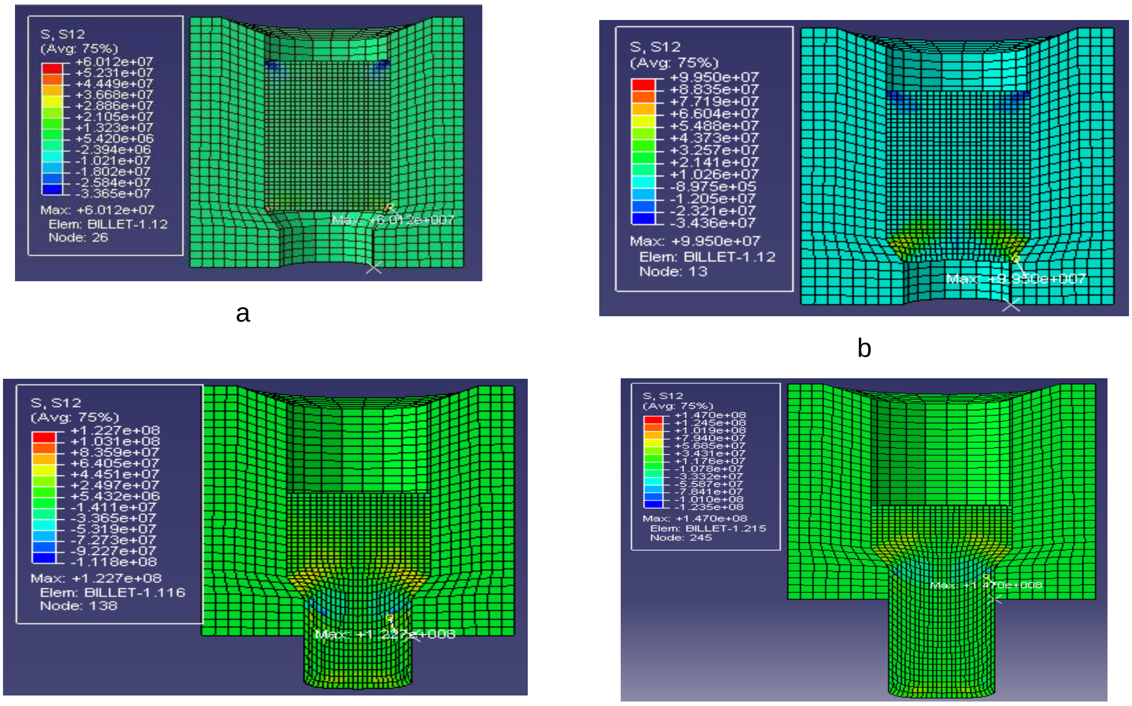

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Figure 3 : Location of maximum shear stress (S_{12}) at different stage of extrusion process for friction coefficient, μ = 0.05 and die angle = 60^o.

The change in the state of principle stress (S_{22}) and plastic strain (PE_{22}) for die angle (α = 60^o) and friction coefficient (μ = 0.05) during the extrusion process can be obviously seen in figures (4 & 5). From figure (4), it is clear that when the billet material flows throughout the die, the material in the corners of container and die was under compressive stress. Also, it can be noticed, the maximum principle stress (S_{22}) which is tensile stress localizes in the surface areas of the extrudate, whilst the compressive stress exists in the core of extruded parts. Figure (5) reveals the changes that have taken place in plastic strain (PE_{22}) through the extrusion process.

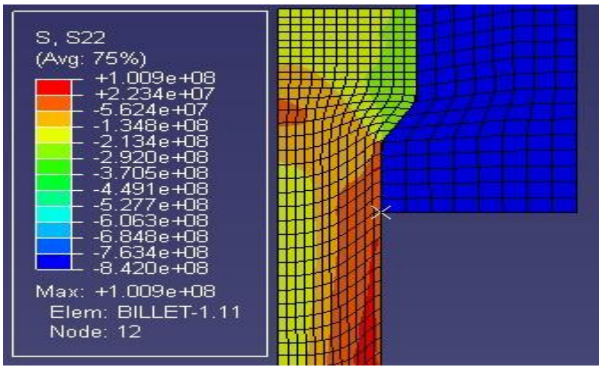

Figure 4: Distribution of principle stress(S_{22}) of extrusion process for die angle = 60^o and friction coefficient, μ = 0.05.

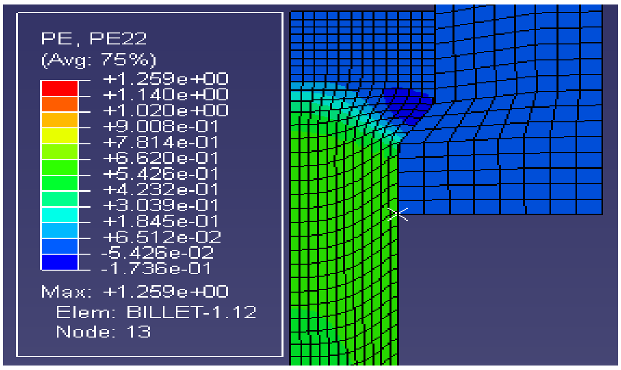

Figure 5 : Distribution of plastic strain (PE_{22}) of extrusion process for die angle = 60^o and friction coefficient, μ = 0.05.

2.1.1. EFFECT OF FRICTION COEFFICIENT ON STRESS DISTRIBUTION

The variation of maximum vonMises stress with friction coefficient for different die angles are shown in figure (6). It is obvious that the increasing of friction coefficient leads to increase the value of maximum vonMises stress. Also, it can be seen, there is a significant effect of die angle in such manner; the bigger the die angle, the less value of maximum vonMises stress is. This can be attributed to the bigger die angle achieve more easily flow of billet material through the die, leading to a decrease in the extrusion force that needed to press the billet to go through the die outlet.

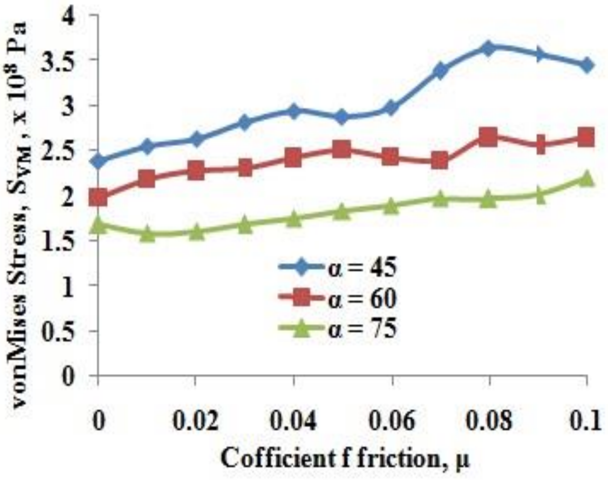

Figure 6: The variation of vonMises stress (S_{VM}) verse friction coefficient for different die angles.

In addition to another parameter that affects on stress and strain state during extrusion process,the frictional condition at the billet – container and billet – die contributes strongly in determining the characteristics of stresses and plastic strain that exist in extruded products. Figures (7, 8 and 9) demonstrates the variation of vonMises (S_{VM}), principle (S_{22}) and shear (S_{12}) stresses with friction coefficient for (60^o) die angles. It is evident that the increasing of friction coefficient leads to increase the maximum values of all stresses. The results accentuated that the maximum values of S_{VM}, S_{22} and S_{12} are (265 MPa, 158.8 MPa and 75.98 MPa) respectively, and for tested cases, these results attained at maximum value of friction coefficient which is equal to (0.1). These results mean, as the coefficient of friction increases, larger frictional forces is, so larger extrusion force is needed to overcome this force which resists the material's flow through the container and die. Then consequently, higher stresses exist during the extrusion process with a high value of friction coefficient.

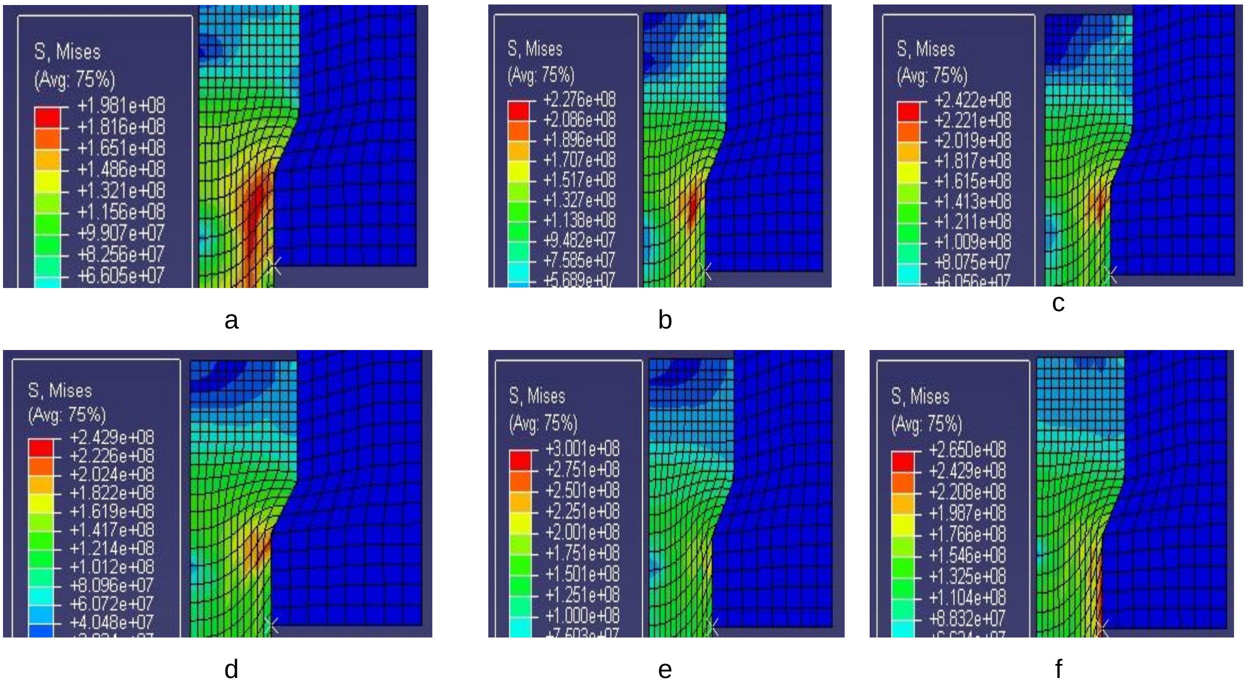

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Figure 7 : Effect of friction coefficient on vonMises stress (S_{VM}) for 60^o die angle ; a- μ= 0.00, b- μ=0.02, c- μ = 0.04, d – μ =0.06, e- μ=0.08 and f- μ = 0.1.

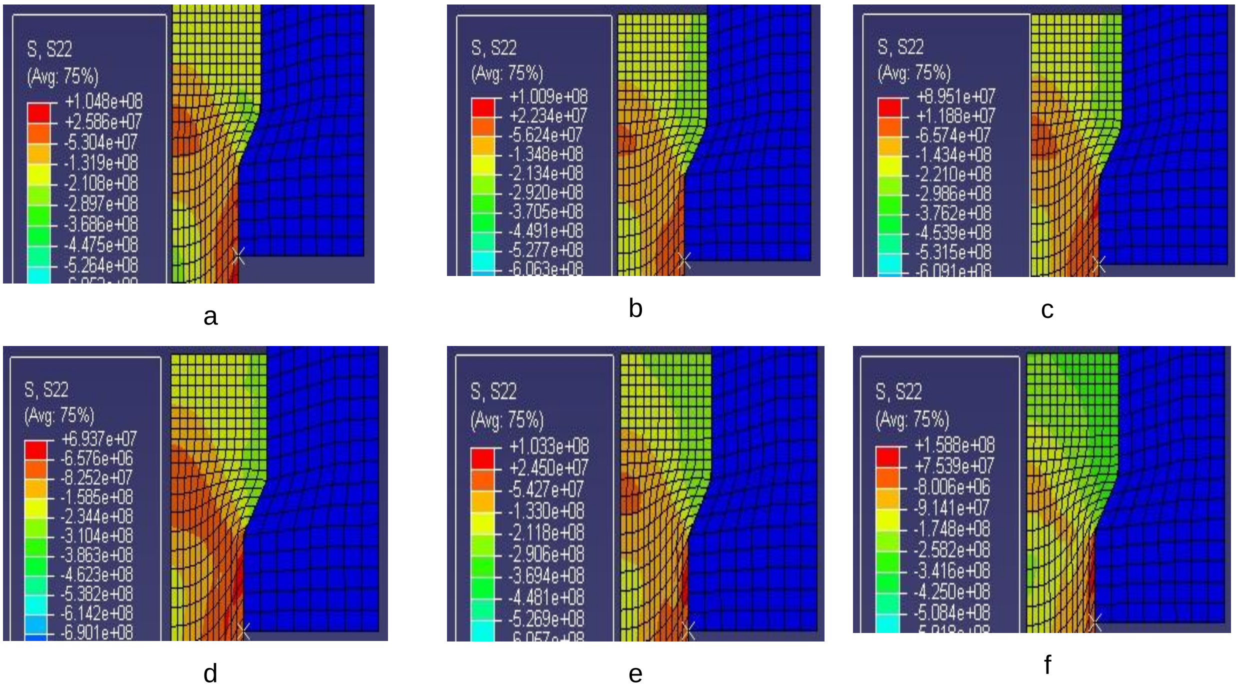

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Figure 8 : Effect of friction coefficient on principle stress (S_{22}) for 60^o die angle ; a- μ= 0.00, b- μ =0.02, c- μ = 0.04, d – μ =0.06, e- μ=0.08 and f- μ = 0.1.

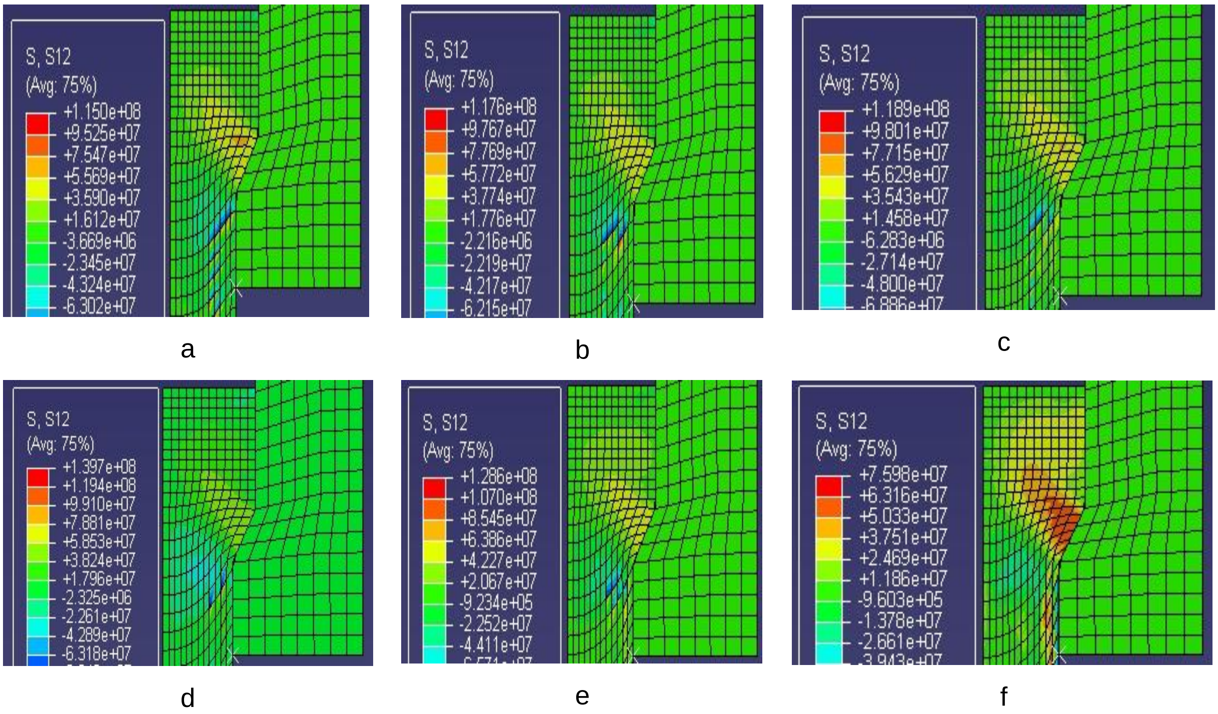

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Figure 9: Effect of coefficient of friction on shear stress (S_{12}) for 60° die angle ; a- μ= 0.00, b- μ=0.02, c- μ = 0.04, d – μ =0.06, e- μ=0.08 and f- μ = 0.1

2.1.2. EFFECT OF DIE ANGLE ON STRESS DISTRIBUTION

Die angle has a direct effect on the level of maximum stresses and strains of extrusion process. The variation of maximum values of (S_{VM} , S_{22} , S_{12}) for different die angles and friction coefficient are shown in figures (10, 11 and 12). The results were exhibited that the maximum values of stress, strain and contact pressures for ($\alpha = 75^o$) die angle are lower than those for ($\alpha = 45^o$). It means, the bigger the die angle, the lower values of maximum stress are. This can be attributed to the fact, the bigger die angle achieves more easily flow of the billet's material throughout the die, hence decreasing the extrusion forces that needed to press the billet to go toward the die outlet and consequently fewer values of maximum stresses and strains. These results are consistent with result have been found by Adeosun S. O. et al.[1].

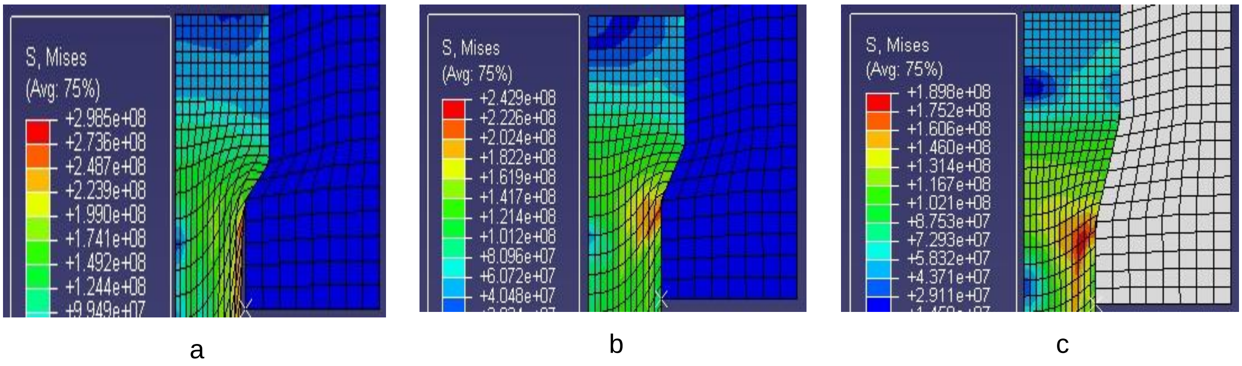

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Figure 10 : Effect of die angles on VonMises stress (S_{VM}) for coefficient of friction μ = 0.06 ; a- $\alpha = 45^o$, b- $\alpha = 60^o$, c- $\alpha = 75^o$.

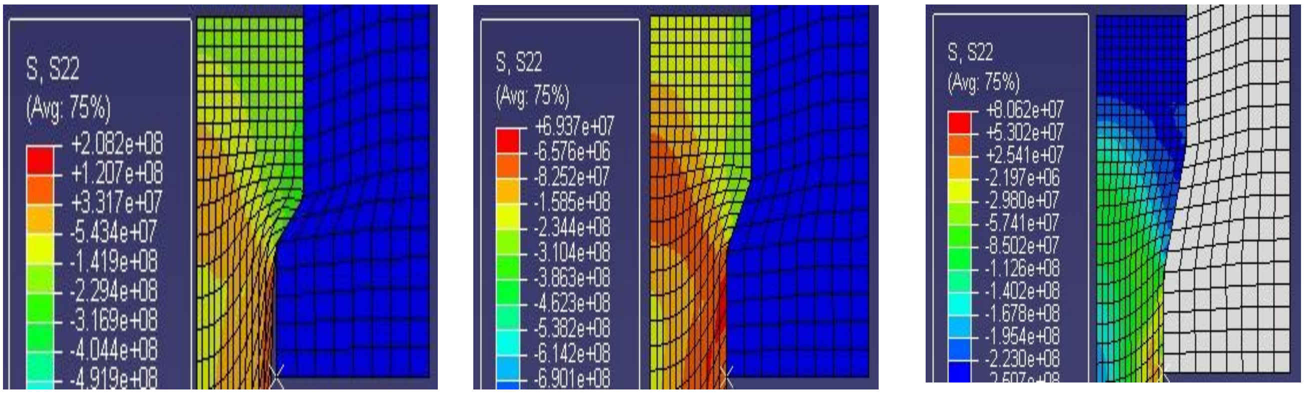

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Figure 11 : Effect of die angles on principle stress (S $_{22}$) for friction coefficient μ = 0.06 ; a- α = 45^o , b- α = 60^o, c- α = 75^o.

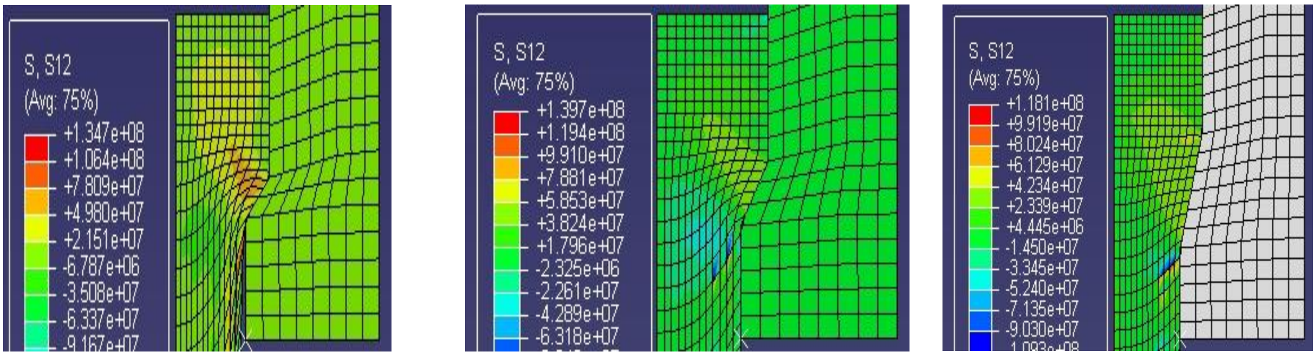

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Figure 12 : Effect of die angles on shear stress (S $_{12}$) for friction coefficient μ = 0.06 ; a- α = 45^o , b- α = 60^o, c- α = 75^o.

2.2. Temperature distribution

The relationship between the maximum temperature and friction coefficient for different die angle is shown in figure (13). It is evident that the increasing of friction coefficient leads to increase the value of maximum temperature.The temperature distribution and location of maximum values of (60^o) die angle for different friction coefficient are illustrated in figure (14). It is clear that the maximum temperature exists on the surface of extrudate part in the region when the material enters toward the die, it is in the interfacial contact surface between the material and wall of the die.

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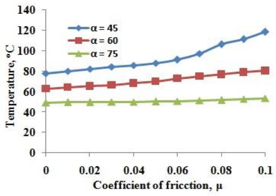
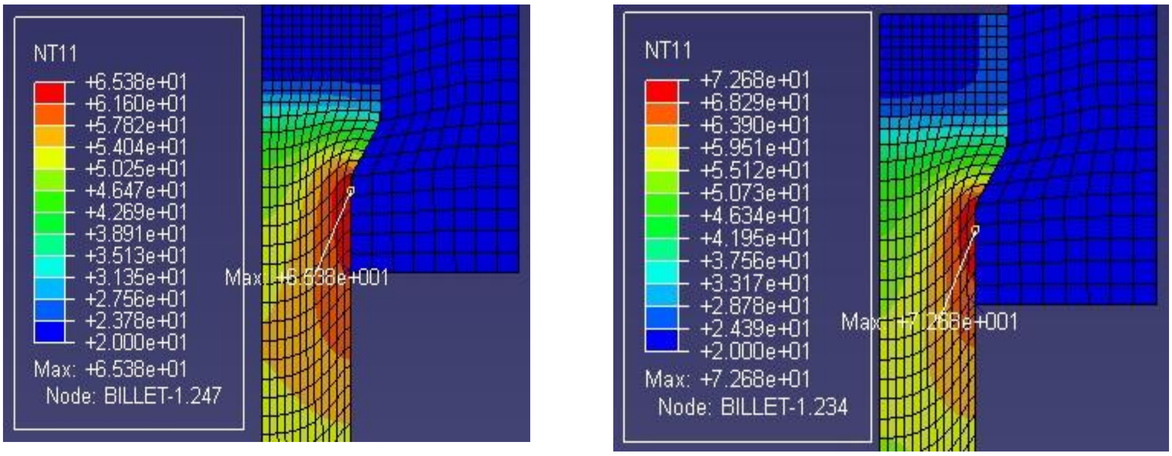


Figure 13 :The releationship between maximum temperature and coefficient of friction for different die angles.



a

b

Figure 14 : Temperature distribution and location of maximum values for 60° die angle and friction coefficient of ; a - μ = 0.02 , b - μ = 0.06.

2. 2.1. Effect of friction coefficient on temperature distribution

The variation of maximum temperature, which generates during the extrusion process for (α = 60°) with different values of friction coefficient, is shown in figures 13 and 15. There is a gradual increasing in maximum value of temperature with increasing the friction coefficient. The maximum temperature for (α = 60°) at frictionless condition is (62.77 °C) and it increases to (80.53 °C) at (μ = 0.1), it means, the the difference percentage is (22%) while for (α = 45°) and (α = 75°) are (34% and 7.6%) respectively. These results prove that, the friction coefficient at the interfacial surface between the billet's material and the walls of both container and die, has a significant effect on the level of maximum temperature which created through the extrusion process. This can be explained as; when the friction coefficient increases, more friction force exist between the contact surfaces and it will produce more heat. Hence the maximum value of material's temperature which exists inside the die will also increase. These results are consistent with results that have been found by Salode A. M. [11].

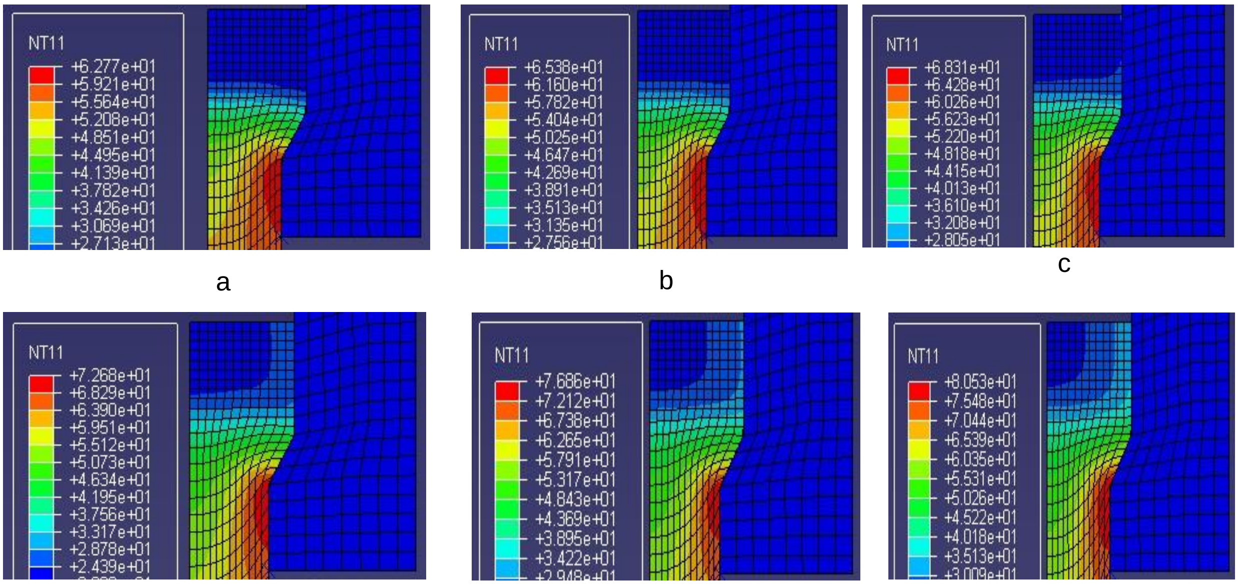


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Figure 15 : Effect of friction coefficient o on Temperature (NTII) for 60° die angle a- μ= 0.0, b- μ=0.02, c- μ = 0.04, d – μ =0.06, e- μ=0.08 and f- μ = 0.1

On another hand, and despite the fact of, materials deform easily at high temperature due to the softening effect, nevertheless the high level temperature which created through the extrusion process, is undesirable because of the intensity of dead metal zone formation will increases. Also, a high temperature affects the elastic and plastic properties of the billet and die material, resulting in increasing the level of plastic deformation of extruded material and/or increasing the deflection of the die [11].

2.2.2. EFFECT OF DIE ANGLE ON TEMPERATURE DISTRIBUTION

The effect of die angle on the maximum value of extruded parts' temperature is shown in figures (16 and 17). There is a reverse relationship between the die angle and maximum temperature. In the range of tested cases of friction coefficient, the maximum temperature for (α = 45°) is higher than that for (α = 75°), and for (μ > 0.08) it is more than twice higher. They are (106.2 °C, 76.86 °C, 51.74 °C) at (μ = 0.08) for die angles of (45°, 60° and 75°) respectively. The results are revealed that the maximum temperature is substantially influenced by the die angle in such a manner; a low die angle leads to difficult flow of material throughout the container and die toward the die outlet, resulting with increasing in the friction at billet – container and billet – die interfaces, which caused large amount of heat generation, consequently increasing the process temperature.

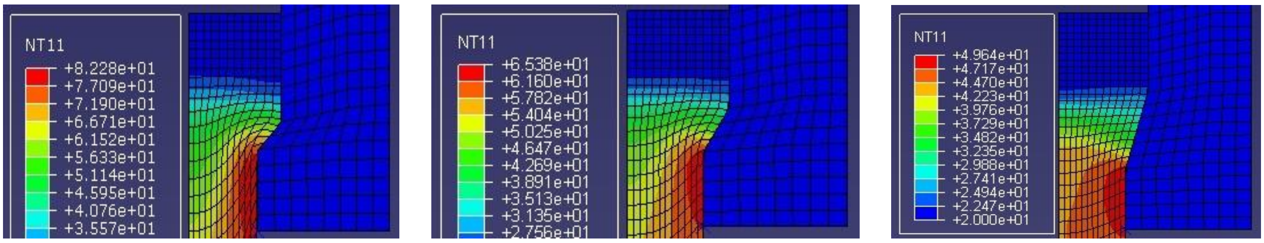

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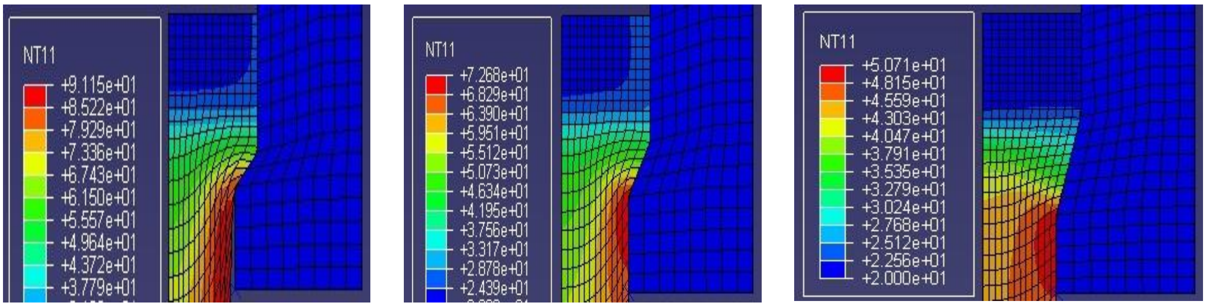
Figure 16 : Effect of die angles on temperature (NTII) for coefficient of friction μ = 0.02 ; a- α = 45°, b- α = 60°, c- α = 75°.



a b c

Figure 17 : Effect of die angles on temperature (NTII) for friction coefficient μ = 0.06 ; a- α = 45º , b- α = 60º, c- α = 75º.

VI. Conclusion

The influence of stress and temperature distribution by die angle and friction coefficient have been investigated using finite element analysis. The die angle has a significient effect on temperature distribution of billet (i.e. high die angle will decrease the temperature distribution and vice versa). Furtheremore, the finite element simulation of process was illustrated that, the maximum values of vonMises stress and temperature are attain at die angle of (45^o) and friction coefficient of (0.1).

REFERENCES

1. **Adeosun S. O., Akpan E. I**. and **Gbenebor O. P**. " Extrusion Characteristics Dependence of wrought Aluminium Alloy on Extrusion Variables ", American Journal of Materials Science, 2013, volume 3, Issue 4, pp. 77 – 83.
2. **Tiernam P., Hillery M. T., Draganescu B**. and **M. Gheorghe**, " Modelling of Cold Extrusion with Experimental Verification", Journal of Materials Processing Technology ", 168, 2005, pp. 360 – 366.
3. **Evan W. Albert**, **Adam T. Barret** and **Timothy F. Gallant**," Study of Direct Aluminum Wire Extrusion by Finite Element Analysis to Mitigate Manufacturing Defects", ME 259 – Computational Solid Mechanics, Final Project Report, May 7 , 2015, pp: 1 – 14 .
4. **Sangamesh Sirsgi**, **Dr. Shrishail Kakkeri** and **Nagraji Patil**, “ Extrusion Process and Parameters Involved in Experimental and Numerical Investigation Review “, International Journal of Engineering Research and Development, Volume 11, Issu 06, June 2015, pp. 01 – 03
5. **Maziar Ramezani** and **Thomas Neitzeert**," Finite Element Modelling of hot Extrusion of Ti – 6AL – 4V alloy ", International Journal of Advanced Engineering Research and Science (IJAERS), Volume 3, Issue – 6 , June 2016, ISSN 2349 – 6495, pp. 45 – 51.
6. **Adeosun S. O., Sekunowo O. I.** and **Gbenebor O. P**. " Effect of Die Entry angle on Extrusion Responses of Aluminium 6063 alloy ", International Journal of Engineering and Technology (IJET), Volume 4, No. 2, February 2014, ISSN 2049 – 3444, pp. 127 – 134, publications UK.
7. **Rafid Jabbar Mohammed**," Effect of Die angle on Stress distribution in Extrusion Process of Aluminium Rod ", Basrah Journal for Engineering Sciences, Volume 14, No. 2, 2014, pp. 43 – 50.

8. **ABAQUS** CAE ver. 6.9, 2009, Example problems Manual; standard User's Manual.

9. **El Amri Abdelouahid** and **Mounir El Yakhloufi haddou**, " Explicit coupled thermo-mechanical finite element of Aluminum Alloys ", International Journal of Recent Advanced in Mechanical Engineering (IJMECH) Volume 4, No. 3, August 2015.

10. **Maziar Ramezani** and **Thomas Neitzer**,“ Computer Simulations of Direct Extrusion of Sintered Ti – 6 Al – 4 V alloy at Elevated Temperature ", International Journal of Applied Engineering Research ", ISSN 0973 – 4562, Volume 11, Number 6, 2016, pp: 3848 – 3852.

11. **Saloda Murtaza Ali**," To Study the Influence of Frictional Conditions and Die Land Length on Component Error and Die Deflection in Cold Extrusion by Finite Element Analysis, "Metallurgcal Engineering (ME), volume 3, Issue 1, January 2013, No. 1, pp. 29 – 38.