Temperature Rise in Al 7075 Cold Wire Drawing Using Finite Element Method

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Abstract

In this work the temperature rise in AL7075 wire drawing is predicted numerically using a 3D finite element model. The commercial code Deform-3D was used to construct the model and simulate the wire drawing process. Aluminum wire of 46.38mm was drawn at room temperature through a conical die with semi-die angle $\alpha=5^{\circ}$ and percentage reduction in area equal to 10%. This case was run for different values of friction coefficient (μ=0.05, 0.075, 0.1, 0.125, 0.15, 0.175, 0.2). The result shows that as the coefficient of friction increases, the temperature rises in linear form. The behavior of temperature rise distribution is studied in details for μ=0.1, for this case the temperature rise in wire during the drawing process is (22.3C^{o}) less than in die (28.7C^{o}), also the location of maximum temperature in the die occurs at the contact area before wire exit from the die.

المستخلص

في هذا البحث تم دراسة توزيع ارتفاع درجات الحرارة عدديا" لسلك من الألمنيوم نوع (AL 7075) . تم بناء نموذج عناصر محددة ثلاثي الأبعاد باستخدام الحقيبة البرمجية الجاهزة Deform-3D لسحب سلك من الألمنيوم ذو قطر (46.38 mm) داخل قالب مخروطي نصف زاويته ($\alpha = 5°$) وبنسبة تقلص في المساحة (10%). هذه الحالة نفذت عند قيم مختلفة من معاملات الاحتكاك (μ=0.05, 0.075, 0.1, 0.125, 0.15, 0.175, 0.2). أظهرت النتائج بأن زيادة معامل الاحتكاك يؤدي إلى زيادة الارتفاع في درجات الحرارة بصورة خطية. سلوك توزيع درجات الحرارة خلال عملية السحب درس بصورة تفصيلية عند قيمة معامل احتكاك (μ = 0.1). أوضحت نتائج هذه الحالة أن أقصى ارتفاع لدرجة حرارة السلك أثناء عملية السحب بلغ (22.3°C) وهو اقل من القالب الذي كان أقصى ارتفاع لدرجة حرارته (28.7°C). أن موقع درجة الحرارة العظمى كان في القالب وبالتحديد في المنطقة القريبة من منطقة الخروج.

1. Introduction

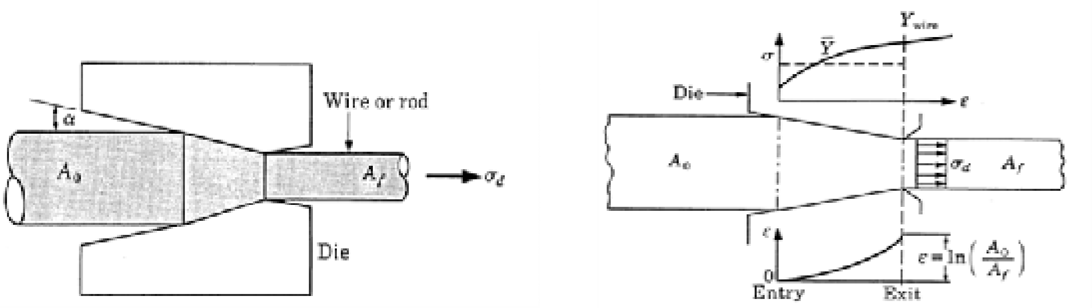
In the wire-drawing process, the cross-section is reduced by pulling it through a conical die, as shown in Figure (1-a). The major variables affecting the drawing process are reduced in cross-sectional area, die angle, friction along the die–work piece interfaces and drawing speed. For a successful drawing operation, careful selection of process parameters should be carried out. The drawing speed depends on the wire material as well as the required reduction in area [1].

There have been many investigators who studied the wire drawing process. Vega et al.[2] investigated the effect of the process variables such as semi die angle and reduction in area, and the coefficient of friction on the drawing force value. For the wire, elasto-viscoplastic behavior is considered, while the die material is assumed to be elastic. Two types of dies have been used in this work: crystal mono diamond core (MD) and crystal poly diamond (PCD). They indicate that friction has significant effects on the drawing force which decrease with the decrease of area reduction. The optimum die angle for wire drawing is assumed to be obtained when the plastic strain distribution across the diameter of the wire becomes uniform. H. Verstam [3] studied the influence of bearing geometry on the residual stress-state in cold drawn wires. The material used was a high carbon steel for roller bearings, 100Cr6. He found that the geometry of the bearing has a large influence of the residual stress-state. Hoon Cho[4] considered the reduction ratio with the size of an inclusion, application of back tension and distance between inclusions in order to investigate the effect of back tension on wire breaks. The size of an inclusion varies 5, 7 and 10 mm, the reduction ratio varies 10, 13 and 16%, the distance between inclusions is set to be 0.25 and 0.5 mm, respectively. Conical dies with a half angle a of 78, which is the value generally used in commercial production. As the FEM code, the commercially available software DEFORM-2D is used. Copper is used for fine wire drawing process that initial diameter is 1 mm and final diameter is up to 50 mm. They found that the damage value rises because the tensile stress in deformation zone increases by applied back tension. The distance between inclusions would not affect wire breaks because the distance is expanded excessively through multistage wiredrawing.

Lucca and Wright [5] discussed the assumptions which might be taken into consideration in predicting the temperature rise resulting from frictional heating in wire-drawing.

The magnitude and the distribution of temperature in the wire-drawing process depends on the initial temperature of the material and die, heat generation due to plastic deformation and friction at the die-material interface and heat transfer between the deforming material, the die and the surrounding environment, such as lubricant and air. The frictional heating however, is concentrated near the wire die interface at the die exit and results in the development of a severe temperature gradient. McAllen[6] and Vega [7] studied the influence of forming conditions and show that , the smaller the die angle, the longer is the contact length, and the size and depth of the deformation zone increase with increasing contact length . Die wear, which occurs at the approach and bearing surfaces due to frictional and heating effects, can rapidly diminish tool life as the work piece is frequently formed at an elevated temperature, superior lubrication is required at the die-wire interface [8].

In this work the commercially available finite element method code software DEFORM-3D is used to obtain the stresses, strains, strain rates and temperature distribution in wire during the drawing process. The material selected to carry out this analyses was an aluminum alloy Al7075, the properties of wire materials at room temperature is given in Table (1). The main object of the present study is to simulate the temperature distribution in wire and die



(a (b

Figure(1). Parameters in the Wire-Drawing, [1].

during the drawing process.

2.Theory of wire drawing

Assuming that plastic deformation work is completely converted into heat and that no heat loss occurs, the temperature rise in the wire is given by[1]:

$$\Delta T = \frac{W_{tot}}{\rho c} \tag{1}$$

The temperature rise given by Eq. (1) is for an ideal situation, where there is no heat loss. In the actual wire-drawing process, heat is lost to the environment, tools and dies, as well as to lubricants and coolants. The total energy per unit volume W_{tot} can be calculated as [1]:

$$W_{tot} = \int_0^{\varepsilon_{1f}} \frac{K\varepsilon_1^n}{(n+1)} f(\mu,\alpha,r)\,d\varepsilon_1 = \frac{K\varepsilon_{1f}^{(n+1)} f(\mu,\alpha,r)}{(n+1)^2} \tag{2}$$

$$f(\mu,\alpha,r) = \left\{\left(1 + \frac{\tan\alpha}{\mu}\right)\left[1 - \left(\frac{A_f}{A_o}\right)^{\mu\cot\alpha}\right] + \frac{4\alpha^2}{3\sqrt{3}}\left(\frac{1-r}{r}\right)\right\} \tag{3}$$

The drawing stress,(σ_d) is given by:

$$\sigma_d = \bar{Y} f(\mu,\alpha,r) \tag{4}$$

The temperature rise at the exit section of the die can be calculated:

$$\Delta T = \left[\frac{K}{\rho c(n+1)^2}\right]\left[\left\{\ln\left(\frac{1}{1-r}\right)\right\}^{n+1}\right] f(\mu,\alpha,r) \tag{5}$$

Where:

$\varepsilon_{1f} = \ln\left(\frac{1}{1-r}\right)$, $r = \frac{A_o - A_f}{A_o}$

3. Finite element modeling of wire drawing

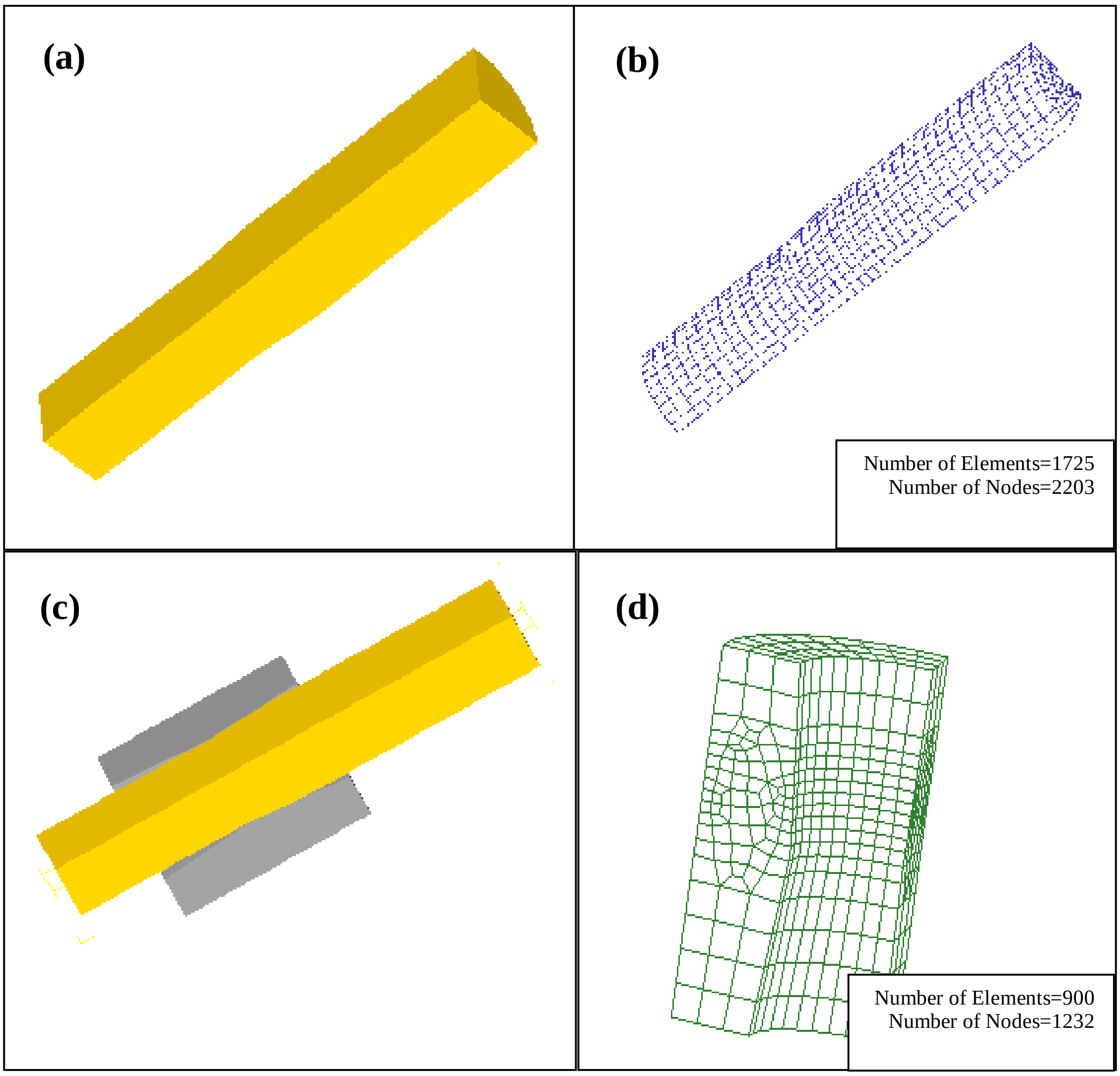
The code DEFORM-3D V6.1 is used to perform finite element analysis of wire drawing process in this research. This software is specifically designed to analyze bulk plastic deformation, and is especially suited for the present analysis. It takes advantage of the fact that plastic deformation is usually highly localized. It assigns rigid elements to the regions of the part that are not deforming, thereby reducing the number of the calculations performed at each step of the simulation. It also updates nodal coordinates using a higher order scheme. This special algorithm accurately takes into account the rotation of the object when calculating new location of the draw part [9]. A 3D finite element drawing model has been constructed to simulate a single pass of wire drawing through a conical die. Due to symmetry only one quarter of the die and wire is simulated, see Figure (2). Aluminum wire of 46.38mm diameter was used as the simulated material in this work. The mechanical properties of wire material at room temperature are given in Table (1) and the valued parameters are given in Table (2).

Table(1). Mechanical properties of Al 7075, [1].

Material	***K (MPa)***	***n***	***Density ρ (Kg/m³)***	***Specific heat c (J/Kg.K)***
Al 7075	400	0.17	2700	900

Table(2). Drawing parameters.

Wire	
Material	Al 7075
Origenal diameter	46.38mm
Final diameter	44mm
Length	160 mm
Reduction in area%	10%
Die	
Material	Rigid
Sime – die Angle	5^o
Exit Angle	3^o
Outer Diameter	80
Inner diameter	44mm
Coefficient of friction between die and wire (μ)=0.1 Drawing speed=111.7mm/s	



Figure(2). (a) Wire before drawing . (b) Meshed wire.
(c) Arrangement wire and die. (d) Meshed die.

4. Results and discussion

To validate the predicted results obtained from the constructed finite element model, it is necessary to compare these results with analytical or experimental data of other authors. The analytical data of El-Domiaty and Kassab,[1] was chosen to achieve this comparison.

The relationship between the temperature rise and coefficient of friction is shown in Figure (3). It is clear that the temperature rises with increase in friction coefficient. This can be concluded to the excess in the frictional work. Also it can be seen from this figure there is a good agreement between the analytical result of [1] and the finite element result of the present work with a maximum percentage error of 5.55%.

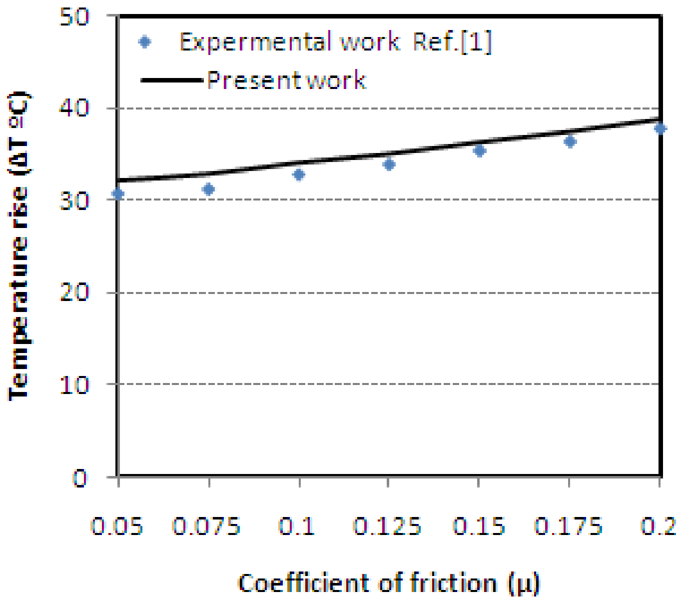


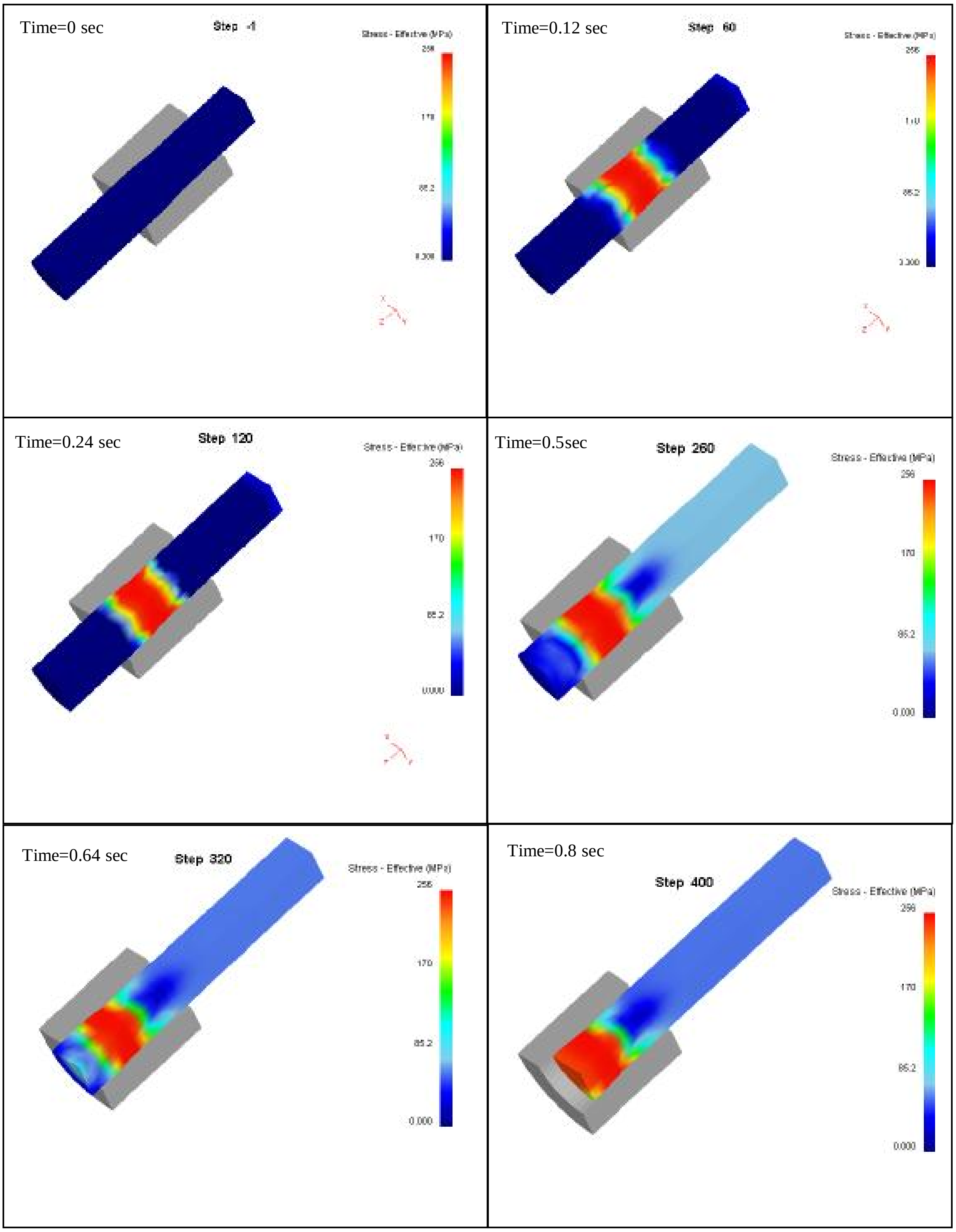
Figure (3). Comparison results of temperature rise as a function of coefficient of friction .

4.1 Distribution of effective stress, strain and strain rate

During cold wire drawing, there will always be a stress of different signs and magnitude. The effective stress, created by material flow, is one of the important types. The effective stress distribution on cross and longitudinal sections in the wire must be in equilibrium. The stress analyses can be conducted to determine stress variation in the material during the wire drawing process. These analyses are very important in the wire drawing process optimization considering low possible contact force. Figure(4) shows the stress distribution in the wire when it passes through the die. The maximum stress value is found near the surface layer of the die-bearing section and maximum stress value is 256 MPa.

A complete distribution of strain along the wire axis when its passes through the die can be observed in Figure (5).Distributions of the strain shows that the maximum value of strain occurs at the exit from the die with a value of 0.235.

Figure (6) shows the distribution of strain rate along the wire axis when its passes through the die. The maximum value of the strain rate in the deformed wire during a temperature change from 25 °C to 53.7 °C was found to be 1.67 s^{-1}.



Figure(4). The contour plot of the effective stress during the drawing process.

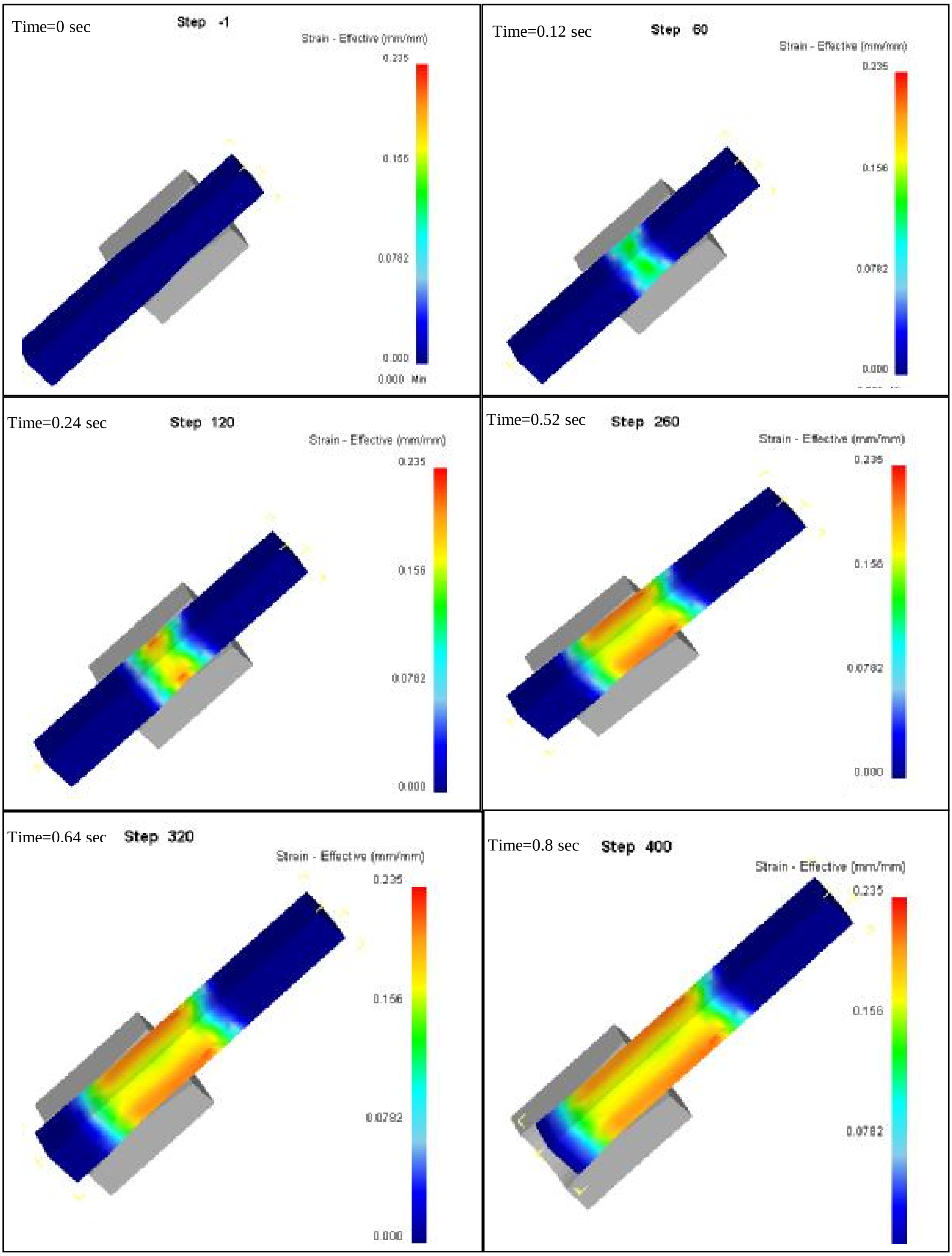


Figure (5). The contour plot of the effective strain during the drawing process.

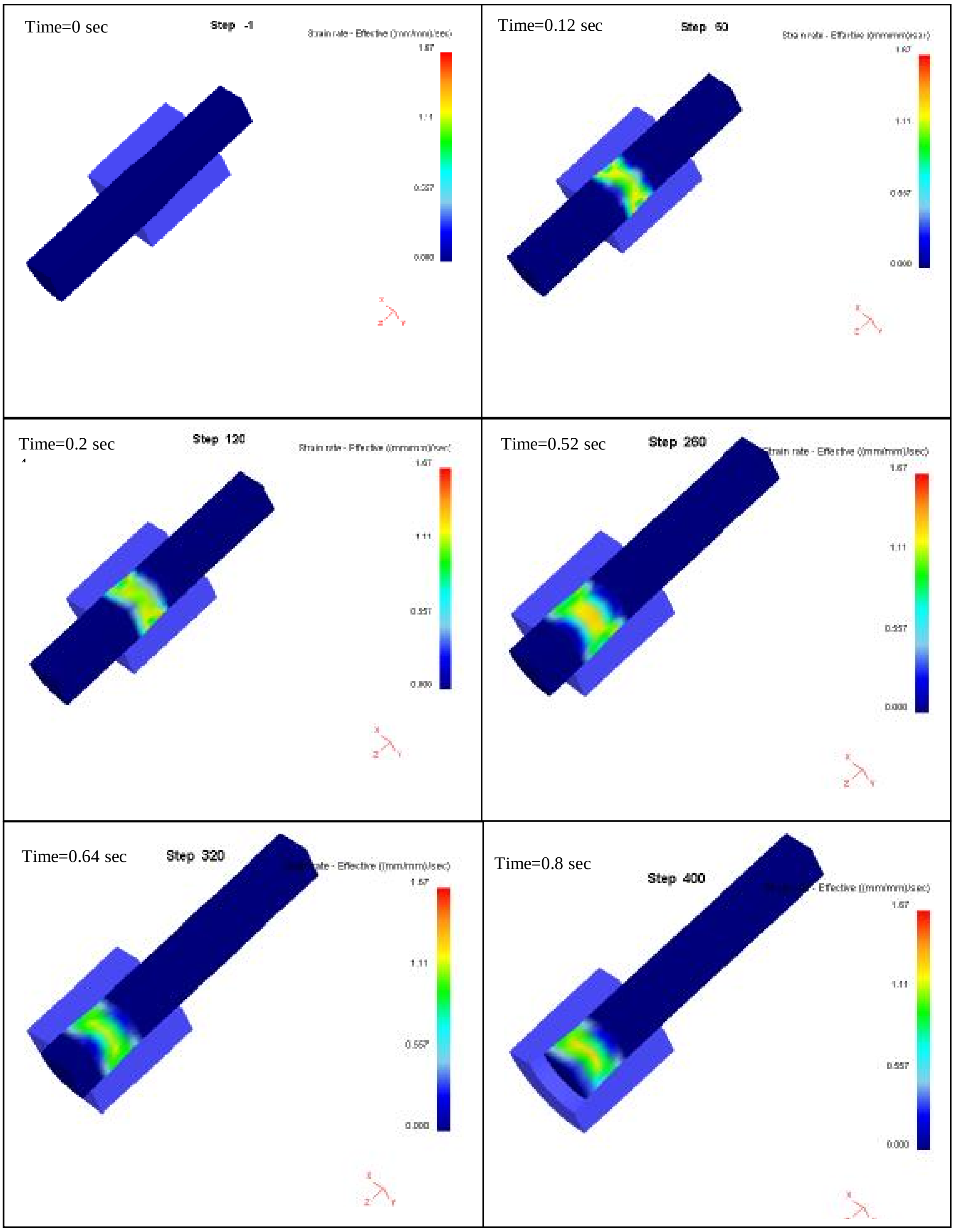


Figure (6). The contour plot of the effective strain rate during the drawing process.

4.2 Temperature evolution during cold wire drawing process

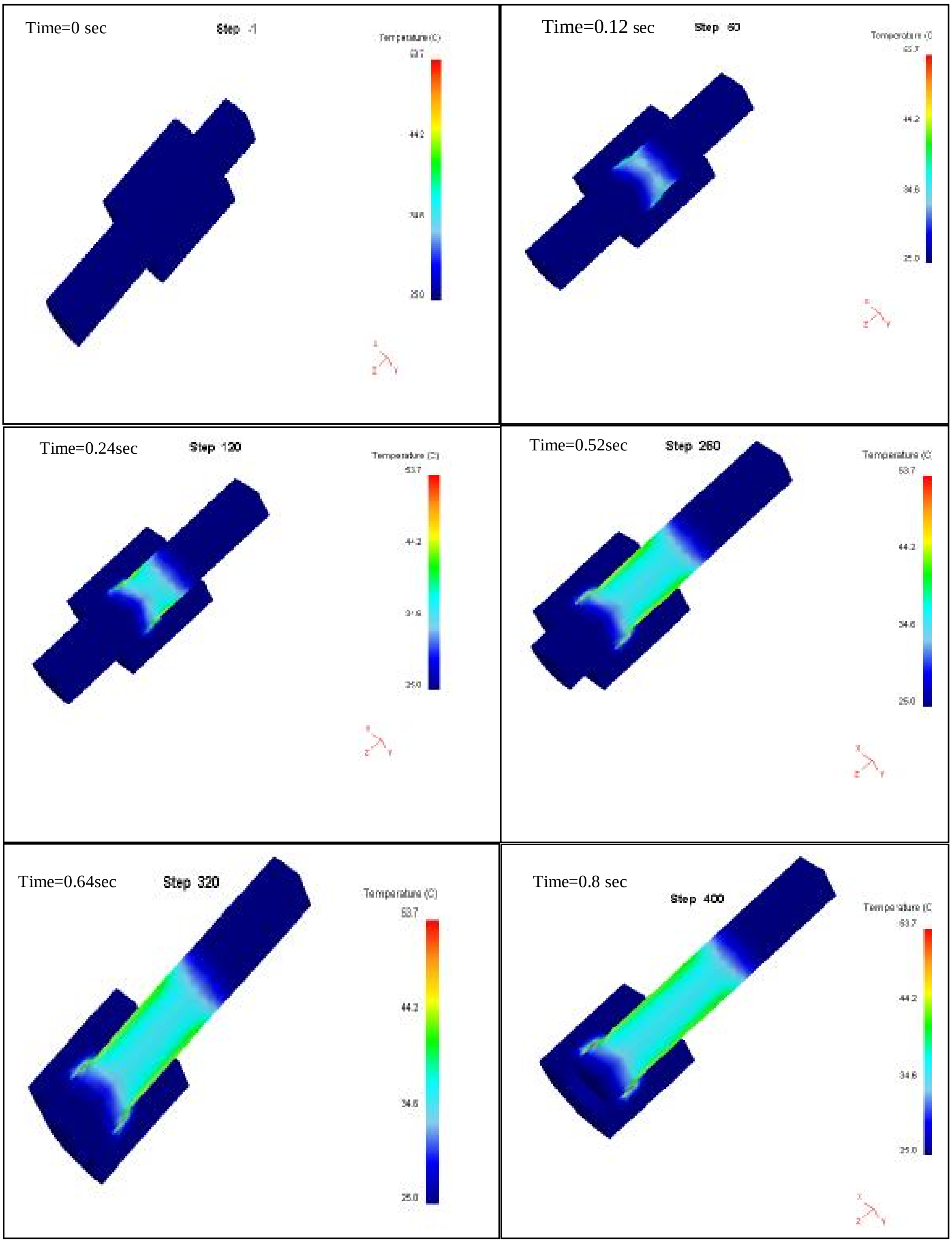
Figure (7) shows the distribution of the temperature on the aluminum *Al* 7075 wire knowing that the temperature of die and wire at the beginning of process is 25°C then the temperature rises during the process and reaches its maximum value 53.7°C in the contact area between the die and wire.

The maximum temperature rise in the wire is at the surface equal to 47.3°C, the heat transfer toward the center of the wire by conduction causes an increase in temperature at this region until it reaches to almost 35°C as shown in Figure (8). Figure (8-b) presents the temperature distribution at the center line of the wire that has been divided into three regions as shown in Figure (8-a). This figure shows that the temperature rise from room temperature at point (P1) (region after deformation) until it reaches to the maximum value almost 35° C at region (II)(during deformation) then temperature reduces until it reaches to the room temperature again at point (P12) which represents the region before deformation .

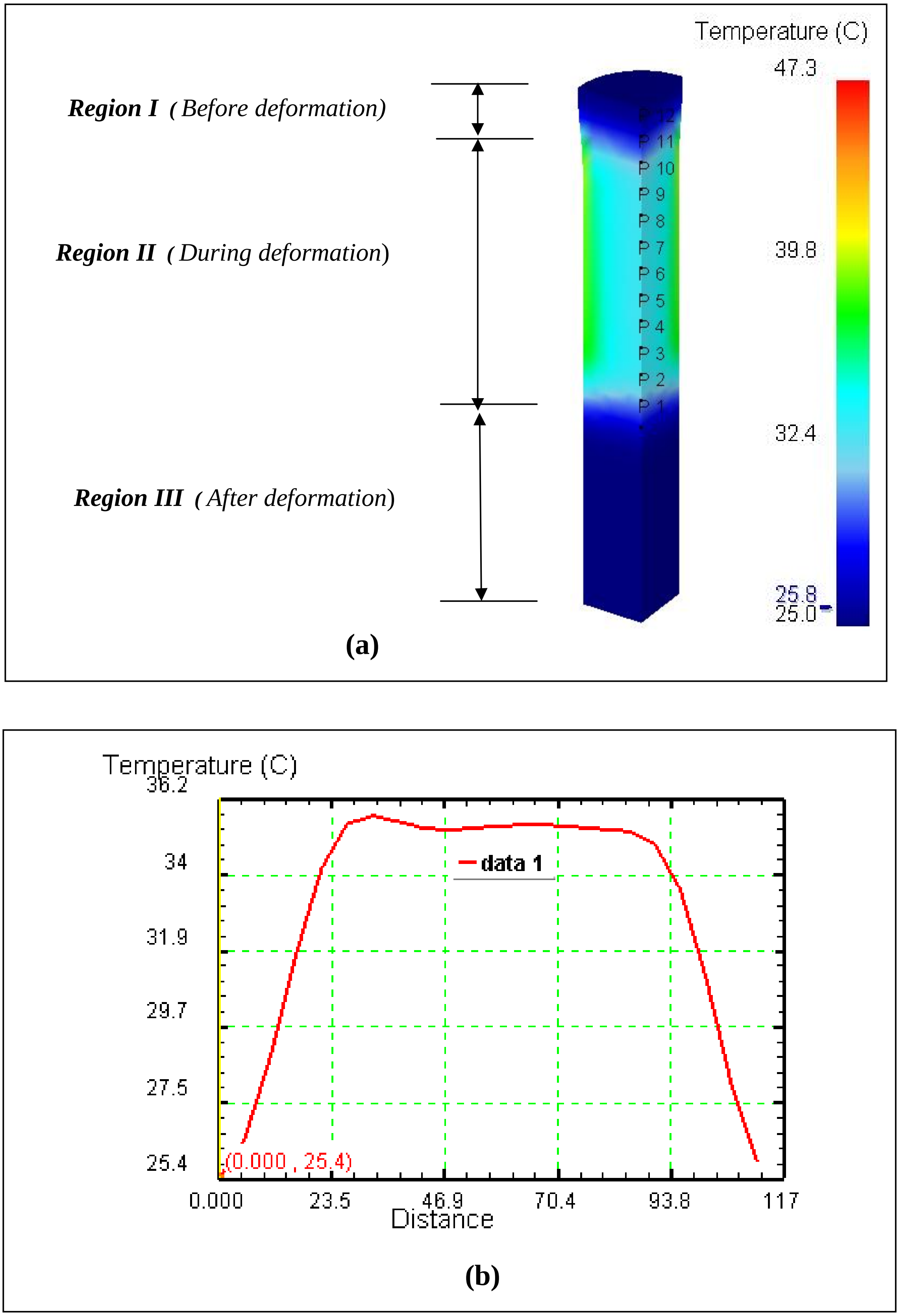
Figure (9) shows the temperature distribution from the center of the wire towards the wire surface. The temperature at the centre of the wire be almost (35°C) increases as we get closer to the surface of the wire where the highest temperature is 47.3°C

The die temperature distribution, see in Figure (10), refers to the maximum temperature which occurs in contact region between wire and die which reach 53.7 ^{o}C . The location of this value at the contact area before the wire exits from the die . This attributed to the increase in the redundant work in this region.

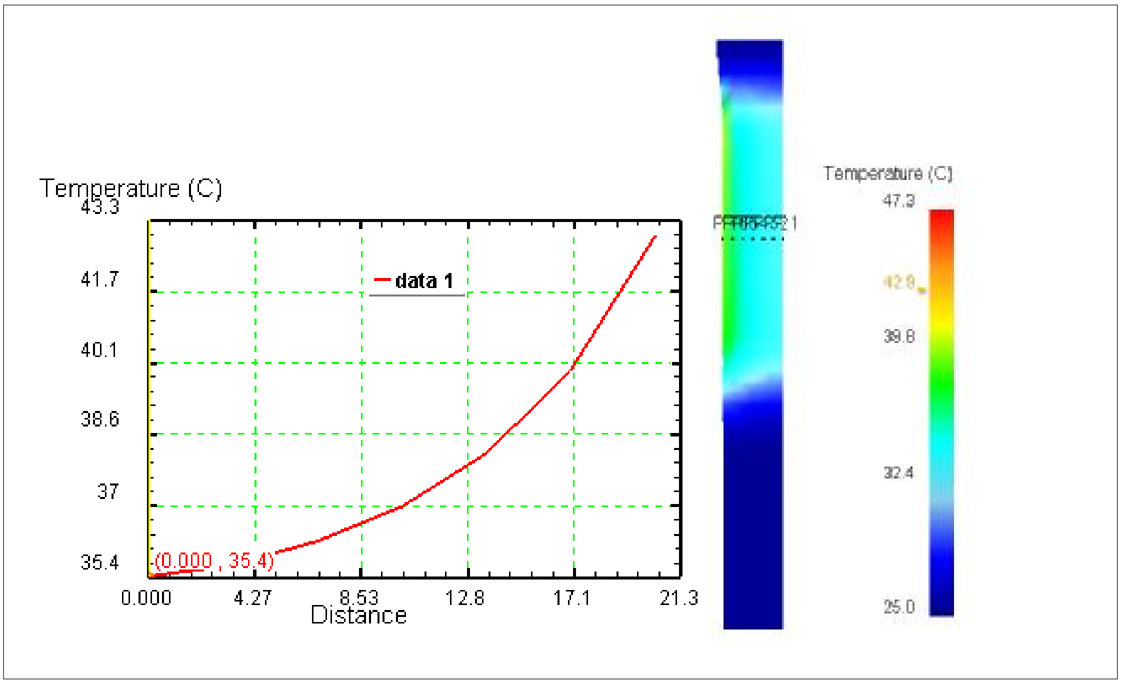
In order to study the temperature change with time on the wire surface, one node on the wire surface is chosen and the temperature change in this node was predicted, see Figure (11). It was noticed that as soon as the wire enters the die the temperature would be raised until it reaches its maximum value at a point close to exit zone then decreases when this point gets far from the exit zone . This behaviour was plotted in time-temperature graph as shown in Figure(12).



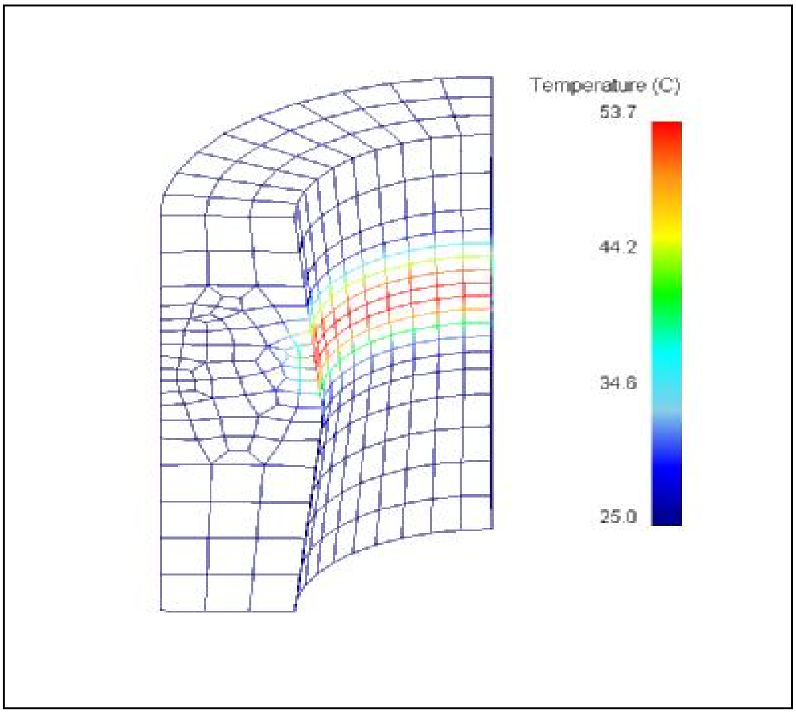
Figure(7). Temperature evolution during cold wire drawing process.



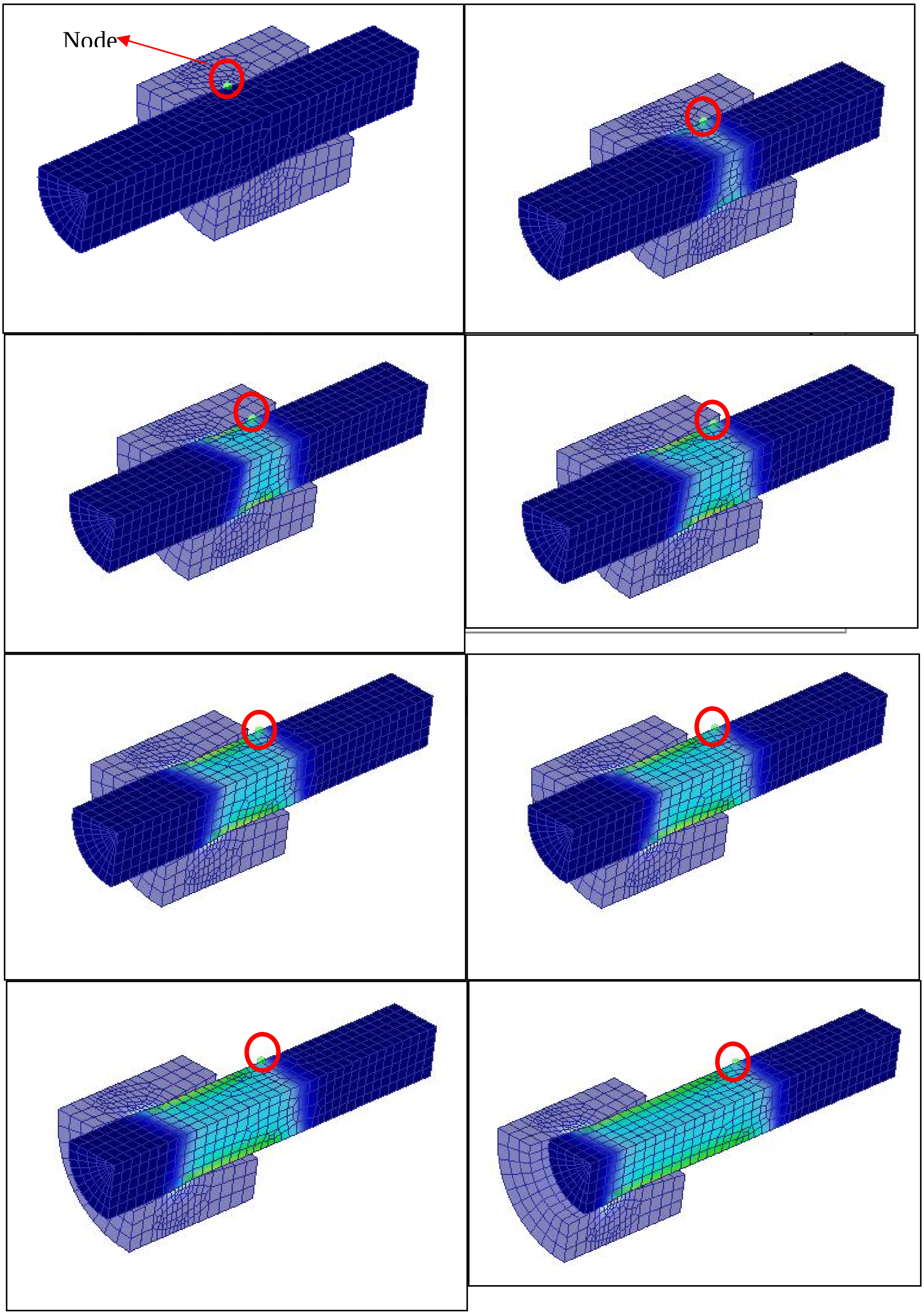
Figure(8). Distribution of the temperature at the centerline in three regions of wire.



Figure(9) . Distribution of temperature rise from the center of the wire towards the wire surface.



Figure(10). Distribution of temperature in die.



Figure(11). Nodal temperature change with change in its location relative to die during the wire drawing process.

5. Conclusions

The following conclusions may be achieved from the results presented in this paper:

1. The results obtained from the present work verify that the process of wire cold drawing could be theoretically estimated using the finite element method with a reasonable degree of accuracy.
2. Temperature rise during the cold drawing process for known conditions could be estimated.
3. The temperature rise in wire during the drawing process is less than in die.
4. The location of maximum temperature in the die occurs at the contact area before wire exits from the die.

6. References

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7. Nomenclature

English Symbols		**Units**
A_o	initial cross-sectional area of the wire material	m^2
A_f	final cross-sectional area of the wire	m^2
c	*specific heat of the wire material*	$J/Kg.K$
K	*strength coefficient of the material*	*MPa*
n	strain-hardening exponent	
r	fractional reduction ratio	
$\bar{Y}$	the average flow stress	N/m^2
ΔT	temperature rise at the die exit	^{o}C
W_{tot}	energy required for drawing per unit volume of the wire	W/m^3
Greek Symbols		**Units**
α	Half die angle in radians	degree
μ	Coefficient of friction	
σ_d	the drawing stress	N/m^2
ε_{1f}	Final axial strain	
ε_1	Axial strain	
ρ	density of the material	Kg/m^3