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Comparison of Different Die Angles on the Deformation during the Process of Wire Drawing Using Three Materials

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Abstract

In a drawing process, the material is pulled, not pushed, through the die. This means that the length of the drawn product is limited only by the storage capacity on either side of the die. Wire is drawn to the correct size by wire drawing. This generally needs to be done in a number of separate passes; each using a smaller die bore than the previous one. Since the reduction in the area in any pass is too great, the drawing force becomes sufficient to make the drawn wire deform plastically (or even break) under the drawing tension. Deformation in drawing is influenced by die angle. Based on split wire die friction studies, redundant deformation influences the level of residual stress in drawn wire.

This paper studies the effect of different die angles on the forming load during wire drawn. This is conducted in two parts: the first part is the theoretical formulas to estimate the coefficient of friction for each considered angle and utilizing the experimental values of drawing force. Based on the estimated values which have been obtained, the second part was creating a numerical model to extend the work to more parameters level as well as check the results validation. The results demonstrated that the die angle of 2° gives best reduction ratio of the wire (30%) compared to other angles used.

Keywords: Wire Drawing, Finite Element Analysis, Reduction Ratio, Friction Factor.

1- Introduction

The wire drawing process for plastic deformation is generated and in consequence of the present force effect and drawing force. The drawn wire and die are heated gradually. The heating of surface layers of the wire is affected by drawing speed, because it affects directly the contact time of the wire with the die. The maximum plastic deformation by the process of wire drawing ranges in the interval of elected angle of drawing cone of die. By great angle of drawing cone, the work for repression of secondary internal materials movement is increased [1].

Different analytical, numerical, empirical and experimental methods have been conducted for decades in order to determine the optimum die angle, which would give the minimum drawing force, in rod drawing process of materials without work-hardening, perfect plastic materials. In these studies, the effects of die angle, friction and area reduction ratio on the optimum die angle have been investigated [2]. An extensive experimental program on wire drawing was carried out in [3], [4] using the upper bound method to the wire drawing process. One most commonly equation adopted in the industrial practice presented by [5]. The equation allows one to compute an upper bound value for the wire drawing force, assuming perfect plasticity for the wire material. The optimum die angle calculated for different high drawing speeds, wire diameters, frictional conditions and mechanical properties of the billet material was given [6]. An attempt has been made in [7] to consider the work hardening effects on optimization of wire drawing forces but their solution was relatively simple [8]. The influence of geometric parameters and the friction condition on the quality of the final wire using finite element

simulation was investigated. One of the main methods today available to study metal forming processes is the finite element method. The optimization of a real industrial process implies parametric studies that involve many different values of the parameters. Using this method, several different models should be developed [8], [9], [10]. Two kinematically admissible velocity fields through hyperbolic and elliptic dies were applied by the slab and the finite element methods to calculate the drawing force necessary to carry out a wire and a plate drawing process in [11].

2-Experimental design and modelling Procedures

2.1- Experiment Design

Changing the dies angle leads to different amounts of elongation of the drawn wire. To explore the effect of changing the die angle, three different materials were used with each tested angle at room temperature.

Table 1 Material categories of the assembled model.

Assembly model	Material of Assembly
Die material	Tungsten Carbide T/C
Wire Material 1	Aluminum (AL)
Wire Material 2	Copper (CU)
Wire Material 3	Carbon Steel (C1018)

This research was conducted using a solid Model prepared by ANSYS software. The model structure consists of two (Assembly) parts: Die and wire. The assembly model is structured and simulated in more than material category; as shown in **Table 1**.

Elongation is proportional with the forming angle of the die.

The dimensions of the model are based on the previous study [12]. The Analytical approach was used as a simulation tool for Finite Element Analysis FEA. As it is widely known, ANSYS can be used successfully to make decisions about the behavior of a component under different situations. The most potential benefit of this tool is the ability of changing the parameters values any time.

In the model preparation, the inlet diameters are 12,10,8,6,4 mm, the outlet diameters are 2,4,6,8,10 mm and the Geometry-angles: Entrance-angle 2β, Exit-/ Back-Relief angle are constant. **Fig.1&2** shows the configuration and dimensions of the experimental die and the 3D-section of the solid model, respectively.

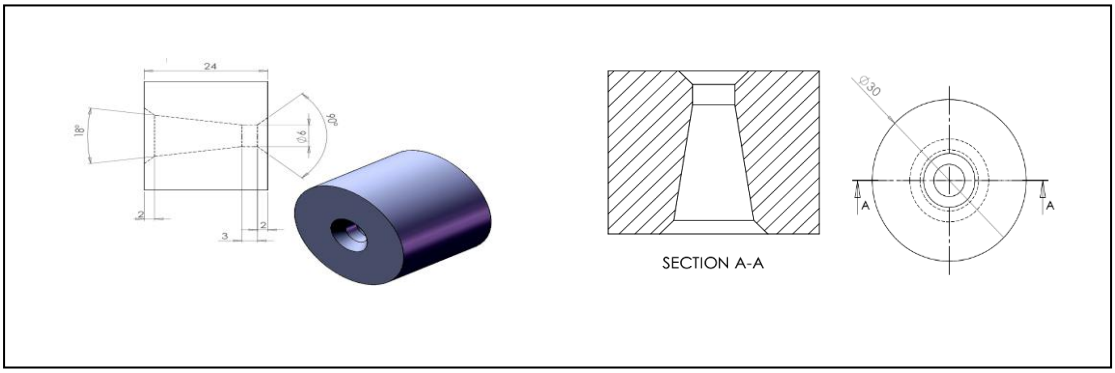


Fig.1 Configuration and dimensions of the experimental die

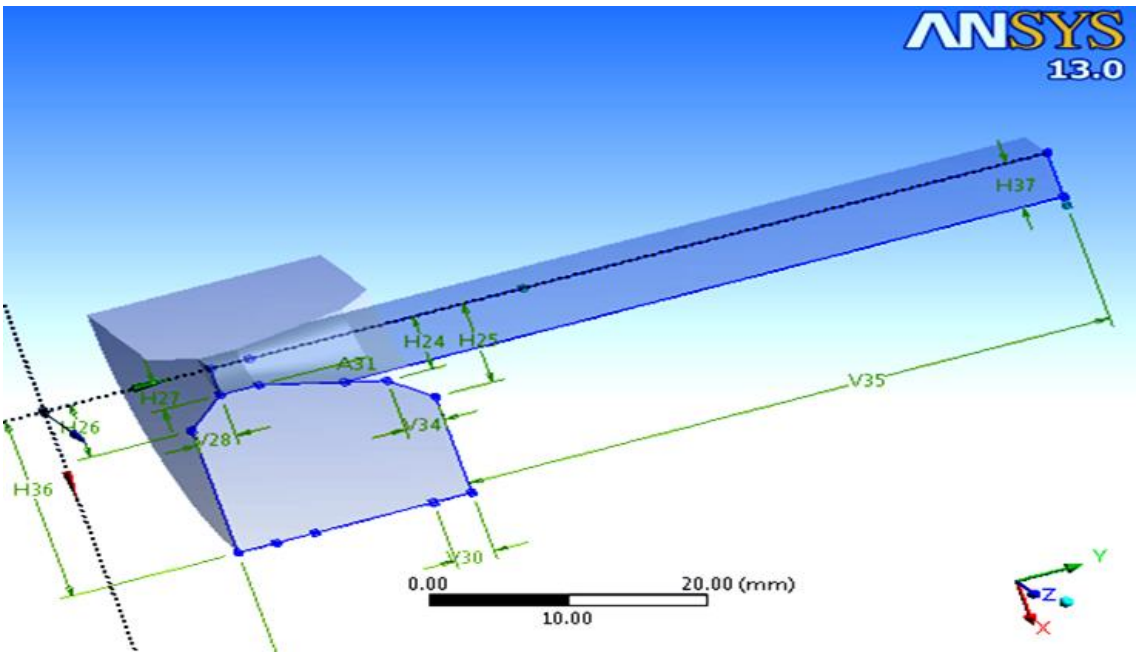


Fig.2 3D-section of the solid model

2.2 Model Constants

Inlet Diameters = 12,10,8,6,4 mm. Outlet Diameters = 2,4,6,8,10 mm.

Die-Materials: T/C

Type of materials used in Experiments Al, Cu and C1018.

Drawing speeds, Friction factors, in every Experiment.

The number of experiments = 2.

The mechanical properties are as shown in **Table 2**, as follows:

Table 2 Mechanical Properties

	Wires Materials			Die Material
Materials types& Mechanical properties	Al	Cu	C1018	T/C
Density (g. cm $^{-3}$)	2.7	8.94	7.87	15.63
Poisson's ratio	0.33	0.36	0.29	0.24
Young's modulus (MPa)	69	110	200	668
Specific heat capacity(J/g.°C)	0.9	0.39	0.49	0.39
Thermal conductivity (Watt/m.K)	235	394	51.9	4.02

3- Results and Discussion

The values of angles must be used according to boundary conditions such as friction ratio, stresses and temperatures arising during the drawing process. For the angles that have been selected in this study are given less stress and therefore give a better life to mold and maintain it for a longer period.

The domain of die angles of [2°, 4°, 6°, 8°, 10°, 12°] and were applied in the experiment, which are represented in the x-axis. Outputs are stresses in (MPa) and Temperatures in (°C), which are represented in the y-axis.

From the experiments conducted in this paper, certain speeds were selected to give the perception and the reality of change on the resulting stresses, and these speeds were not considered high (from 1 m/min up to 1.8 m/min) as shown in **Table 3**.

Table 3. Summarized the optimal angles

Wire material Al				
Speed m/min		1.0	1.2	1.8
Friction Factor	0.1	14	12	8
	0.2	10	12	8
Wire material Cu				
Speed m/min		1.0	1.2	1.8
Friction Factor	0.1	14	12	8
	0.2	10	12	8
Wire material C1018				
Speed m/min		1.0	1.2	1.8
Friction Factor	0.1	14	12	8
	0.2	10	12	8

Therefore can thus obtain optimal angles at these three speeds and when the friction factor of 0.1 to 0.2. This friction reflects the value of the heat produced when the process between the mold and the metal friction given varying values depending on the type of lubricant used, **Table 4**. illustrate the different stresses causes by different angle degrees.

Table 4 Stresses of different die angle degrees for diameter 12 to 6 mm

Model (1)		Φ=12→ Φ6 mm			**Outputs analysis**			
Speed= 0.60(m/min)					**Friction Ratio=**0.10			
Wire Material		**Angels (degree)**						
		2	**4**	**6**	**8**	**10**	**12**	**14**
Stresses (MPa)	Aluminum	158	205	243	285	318	379	416
	Copper	252	326	386	453	505	603	666
	Steel	459	595	705	827	925	1068	1193
Temp. ˚C	Aluminum	22	23	23	23	23	23	23
	Copper	22	23	23	23	24	24	24
	Steel	23	24	24	25	26	27	27

The results of the experiment were obtained using finite element method (ANSYS) for Aluminium, Copper and Carbon steel materials. The obtained results showed that there is a direct proportional relationship between the stresses and die angles as illustrated in **Fig.3** for any increase in the drawing angle, the stress increases because the deformation pressure on the drawn metal increases with an increase in the generated temperature at the die because of the friction ratio.

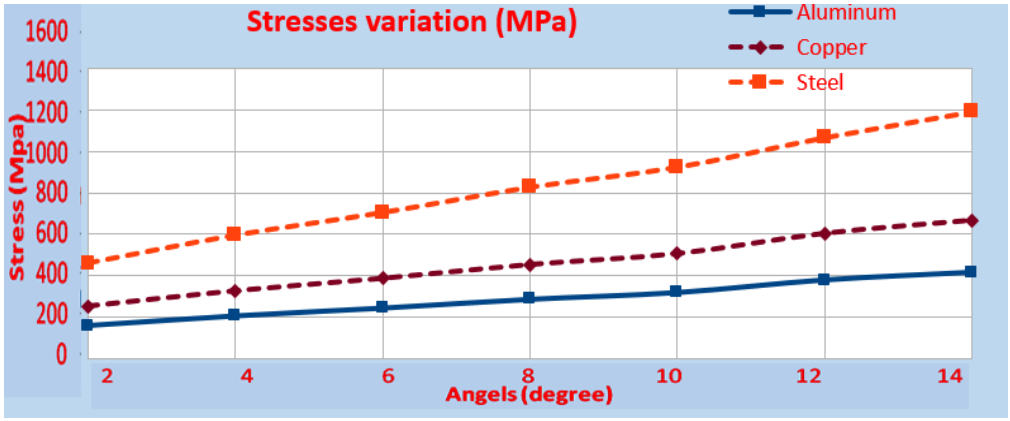


Fig. 3 Stresses variation against die angles degree for diameter 12 to 6 for speed of 0.6 m/min and friction ratio of 0.1

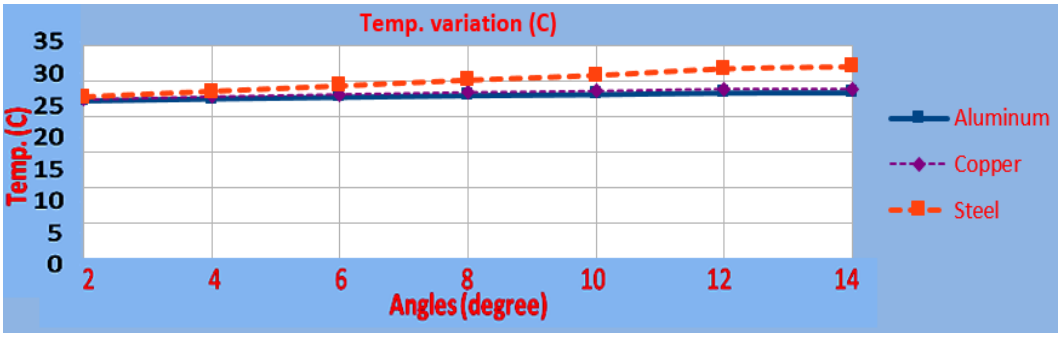


Fig. 4 Temperature variation against die angles degree for diameter 12 to 6 for speed of 0.6 m/min and friction ratio of 0.1

In this experiment, the stresses increase with an increase of the friction for the same speed of the experiment number 1, as illustrated in **Fig.5,** it was found that the stresses were dependent of the friction between the die and metal as shown in **Table** 5. Similarly, the relation between stresses and the friction is directly proportional as shown in **Fig. 5. & 6.**

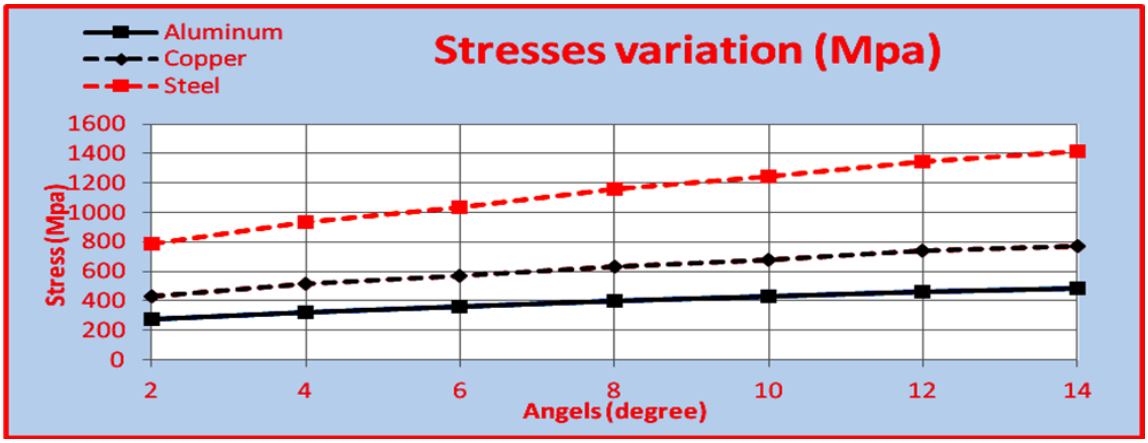


Fig.5 Stresses variation against die angles degree for diameter 12 to 6 for speed of 0.6 m/min and friction ratio of 0.2.

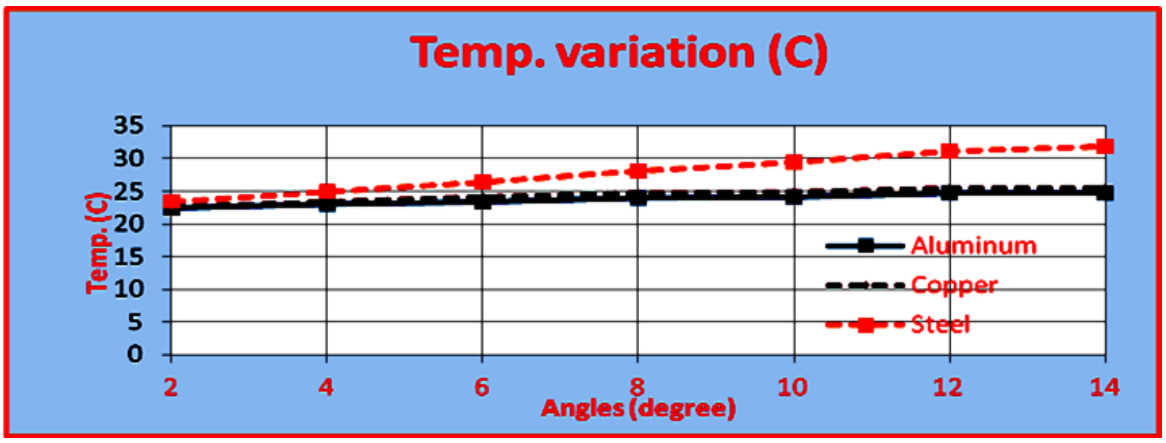


Fig. 6 Temperature variation against die angles degree for diameter 12 to 6 for speed of 0.6 m/min and friction ratio of 0.2

Table 5 Stresses of the die angle degrees for diameter 12 to 6 mm for speed of 0.6 m/min and friction ratio of 0.2

Model (2)	D = Φ12→ Φ6 mm	**Outputs analysis**						
Speed= 0.60(m/min)					**Friction Ratio=**0.2			
Wire Material		**Angels (degree)**						
		2	**4**	**6**	**8**	**10**	**12**	**14**
Stresses (MPa)	Aluminum	272	322	357	399	428	464	487
	Copper	433	513	568	634	680	737	773
	Steel	789	934	1036	1157	1242	1349	1416
Temp. °C	Aluminum	22	23	23	24	24	25	25
	Copper	23	23	24	25	25	26	26
	Steel	23	25	26	28	29	31	32

This analyses and the next two is diferent with the all previouse analyses. the result curve between stresses agains reduction ratio of wire drawing diameter from 8% to 50% as illustrated in **Fig.7**. Although we will not drawing wires in these angles because it located in the area of flexibility in the stress strain diagram. The curve showed directly proportional relationship between stress and reduction ratio of wire drawing diameter specialy for angle 4°. For any increase in the reduction ratio, the stress increases because the deformation pressure on the drawn metal increases with an increase in amount of metal that witch deformed and also increase the generated temperature at the die because of friction. This experiment shows that the best drawing of reduction ratio of wire drawing diameter is between 33% to 40% as illustrated in **Table 6**. and **Fig.8**.

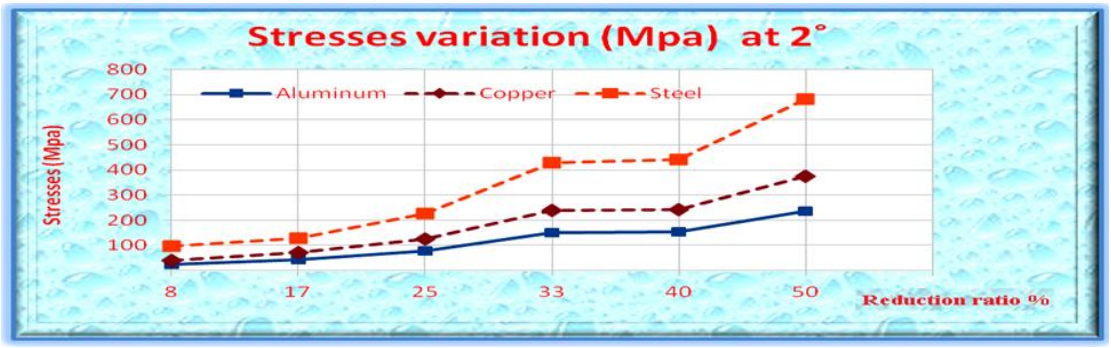


Fig.7 Stresses variation against wire diameter reduction ratio for die angle 2° for speed of 1.5 m/min and friction ratio of 0.1

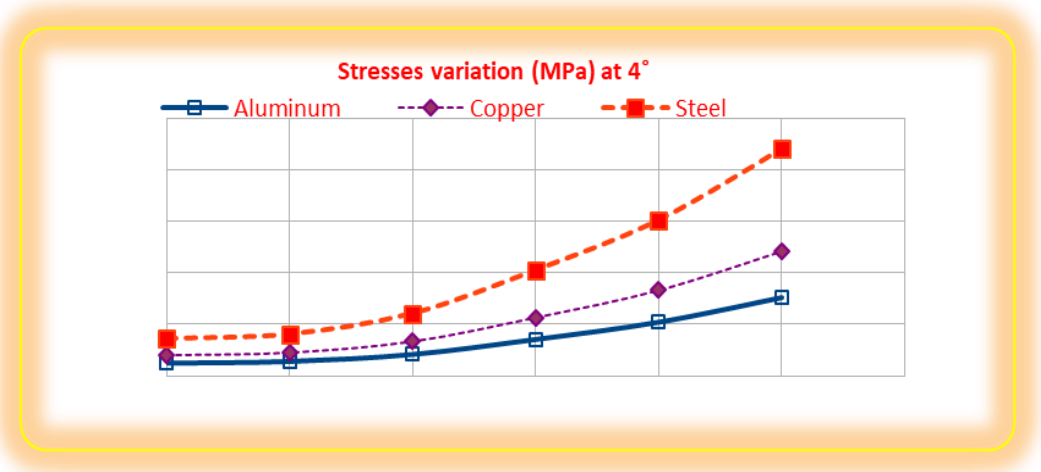


Fig. 8 Stresses variation against wire diameter reduction ratio for die angle 4° for speed of 1.5 m/min and friction ratio of 0.1

Table 6. Stresses of various wire diameter reduction ratio of die angles 2 and 4 degrees for speed of 1.5 m/min and friction ratio of 0.1.

Analysis (1)		Degree 2° and 4°		**Outputs analysis**			
Speed= 1.50 (m/min)					**Friction Ratio**= 0.10		
wire material		**Reduction of D %**					
		8	**17**	**25**	**33**	**40**	**50**
Stresses (MPa) at 2°	Aluminum	26	44	78	151	152	235
	Copper	41	70	124	240	242	374
	Steel	97	128	226	428	441	682
Stresses (MPa) at 4°	Aluminum	50	56	83	142	209	305
	Copper	79	89	133	226	332	485
	Steel	143	162	242	411	606	883

6- Conclusion

In this study, a comparison has been performed using different die angles on the deformation during the process of wire drawing for aluminium, copper and low carbon steel. It is noted in this theoretical study of the formation processes of the process of wires drawing that the idyllic angles of the operation processes are located in the plastic zone in the stress-strain curve and either angles where the stresses are few or upward it will be in elastic region of the curve mentioned, so it excludes 4o angle because the metal drawn is not formed in the required form due to the elasticity of the metal in this area.

In this study it has been found that there was relationship between the drawn diameter wire and die angles. For each wire diameter has a perfect die angle where the maximum stresses at the lowest value, and this has been also proven by previous studies. From the results conducted at room temperature, it can be concluded that the temperatures had no effect on the stresses during the operations of wires drawing. When conducting operations process at elevated temperatures, this lead to increased plasticity of metal and reduced the level of maximum stress resulting from the drawing operation. The stresses are relatively high at large angles. The results have demonstrated that the die angle of 2° gives the best reduction ratio of the wire by 30% compared to other die angles used.

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