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Elevated Temperature Wire Drawing Process Using AzadirachtaIndicaAndJ.Curcas Seed Oil As Lubricants

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Abstract: *Generally, exploration of the mechanics of wire drawing has been confined to cold working, for which the effects of strain rate and temperature on the flow stress can be neglected. The work in this paper described intensively elevated temperature wire drawing process usingazadirachtaindica and J.curcas seed oil as lubricants, both lubricants were found suitable and dies at temperatures varying from room to 850^{0}C. The dies used were made from Hot-pressed Silicon nitride, Tungsten Carbide, High- Speed Steel. The experimental drawing process was carried out with mild steel and medium carbon steel rod of 8 and 10mm diameter respectively at temperatures varying fromambiant to 850^{0}C. An upper bound solution was used to describe and predict the process of deformation at the stress and temperature distribution profile along the work-piece.The reduction of area achieved was in the range of 40 – 48%.Furthermore,it was established that wire can be drawn at elevated temperatures using the above mentioned lubricants.*

Keywords*: Wire-drawing, Elevated temperature, Mild steel, Medium carbon steel, Azadirachtaindica and J. curcas seed oil.*

I. Introduction

Following the development of drawing industry in recent years, there have been noticeable drawing technology developments to improve process efficiency and quality of drawn wires (M. Suliga, 2014; andKnych*et al.*, 2011). In general, exploration of the mechanics of wire drawing has been confined to cold working, due to the fact that it is performed at a room temperature. Sometimes it may be performed at elevated temperatures for large wires to reduce applied forces (Cem, 2012). This paper described intensively elevated temperature wire drawing process using azadirachtaindica and J. curcas seed oil as lubricants, both lubricants were shown to be satisfactorilly and dies at temperatures varying from ambient to 850°C.

Hot working in a wire drawing operation significantly decreases high flow stress and tool force of the material and as well increases the area of reduction in a single die (Khan et al., 2016).

Azadirachtaindica originates from South East Asia. It is naturally very surplus in most part of Nigeria and is presently used as anti-malaria, pesticide and insecticides. Its potential as a quenchant has also been reported. (Hassan et al, 2011).Consequenly, a jatrophacurcas has many applications such as biodiesel, cosmetics, e.t.c.The reason of selecting both oil as a base stock was it does not contend with the food and its potential as a lubricant has not been exploited on drawing processes.

Classification of Drawing Theories and its concept

A number of researchers have carried out works on deformation processes using various methods of analysis.Byron *et al, (*2010) view wire drawing as a process that pulls the rod manufactured in the groove rolling process through a die with a hole by means of a tensile force applied to the exit side of the die. Elevated-temperature drawing is the most convenient process for drawing materials which are difficult to cold draw. Moon and Kim, (2012) carried out extensive work on the drawing at temperatures up to about 700°C. The reduction of area they achieved was in the range of 40 – 45%. The upper-bound solution was applied to predict the drawing stress, taking into account the drawing temperature, the drawing speed and the area reduction assuming a constant friction factor.(Kuznetsova, et al., 2007) considered the wire drawing operation under hydrodynamic friction whose viscosity is a linear function of pressure. He obtained accurate analytical solutions for the velocity and pressure distribution over the clearance between the moving wire and the pressure pipe lengthwise and through depth.Basically, drawing theories are classified as follows:

i. Equilibrium approach
ii. Slip line field
iii. Upper bound solution
iv. Energy approach
v. Visioplasticity
vi. Finite element method

However, a comprehensive review is presented only for the the upper bound approaches which form the basis of the method used to obtain solutions for the drawing of mild steel and medium carbon steel rod of 8 and 10mm diameter respectively at elevated temperatures. Figure 2.1 is the velocity field assumed in Avitur's theoretical model wire drawing process.

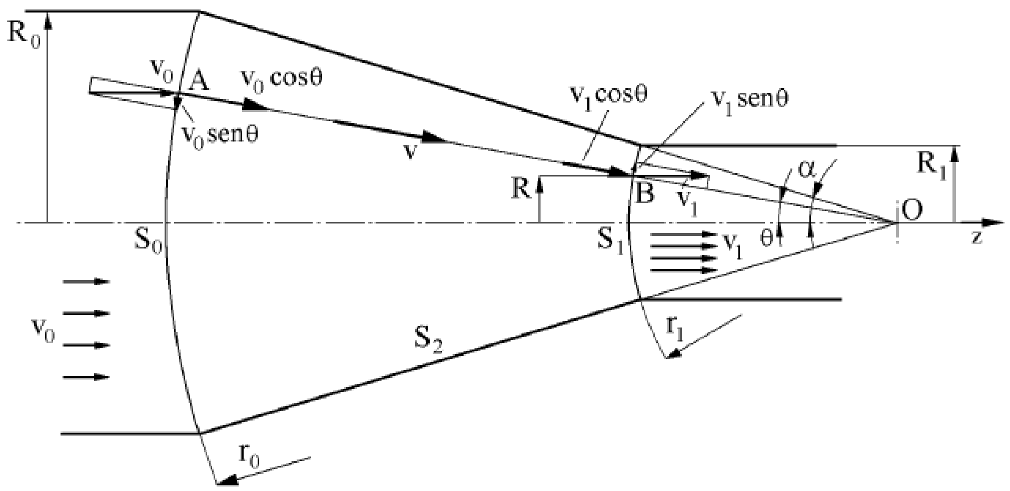

Fig. 2.1 Model of the Velocity field Assumed in Avitzur's Theoretical Model of Wire Drawing Process (1997).

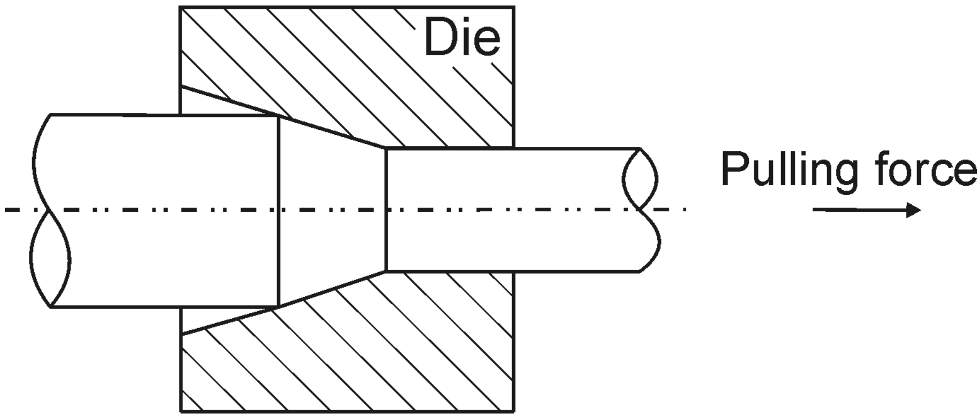

Fig. 2.2 Wire Drawing Concept

Forces and Energy in Wire Drawing

Forces and power in wire-drawing could be analyzed by using simple tension, deformation conditions in wire are, infact, far more complex due to compressive and drag forces generated by the die surface. Figure 2.4 show free body diagram of the forces acting on a wire. Draw force, F, represents the total force that must be applied at the die block to overcome friction at the die surface and resistance of the deforming material. Because the draw force is being transmitted by unsupported material, the draw force must be limited to prevent any plastic deformation from occurring outside of the die. Thus, yield stress of the drawn wire represents an upper limit to the allowable draw stress. Accepted drawing practice normally limits drawn, stress to 60% of the yield strength of the drawn wire. Draw stress is found by dividing the draw force by the cross-sectional area of the drawn wire.While it would appear that the work or energy consumed at a given draw stand is dictated by the material and reduction taken, the actual amount needed is considerably higher in practice. This is the result of inefficiencies that exist during deformation, which are primarily governed by the approach angle. Such inefficiencies do not make any useful contributions in reducing the cross-sectional area and generally serve only to increase energy requirements and adversely influence wire quality. The total work consumed at a draw stand can be partitioned into three components as indicated in figure 2.3 below.

These are:

i. Useful (homogeneous) work required to reduce the cross section
ii. Work required to overcome frictional resistance, and
iii. Redundant (inhomogeneous) work required to change the flow direction.

Homogeneous work is determined by drafting (reduction), and is essentially independent of the approach angle. Friction and redundant work, on the other hand, are closely coupled to die geometry and have an opposite effect as the approach angle is changed. Under normal drawing conditions, typical losses are on the order of 20% for frictional work and 12% of redundant work.

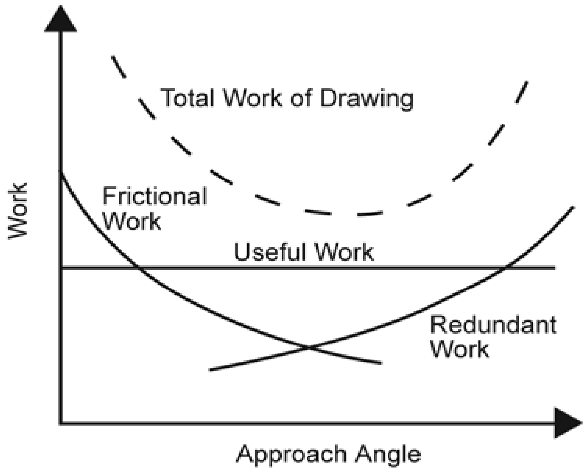

Fig. 2.3 Components of work that operate during wire drawing

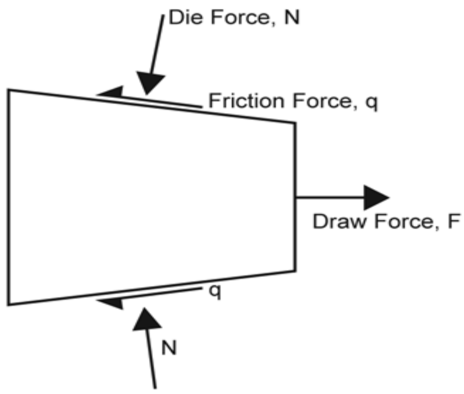

Fig.2.4 Free body diagram showing primary forces in wire drawing

II. Materials And Methods

The main objective of this paper is the evaluation of the lubrication efficiency in wire drawing at elevated temperature, in order to obtain different conditions for lubrication and to evaluate the performance of the lubricants and the pressure die box, two different drawing materials, five different area reductions, five drawing speeds and two lubricants were employed in the drawing tests as shown in the figure 3.1 of the methodology flow chart below.

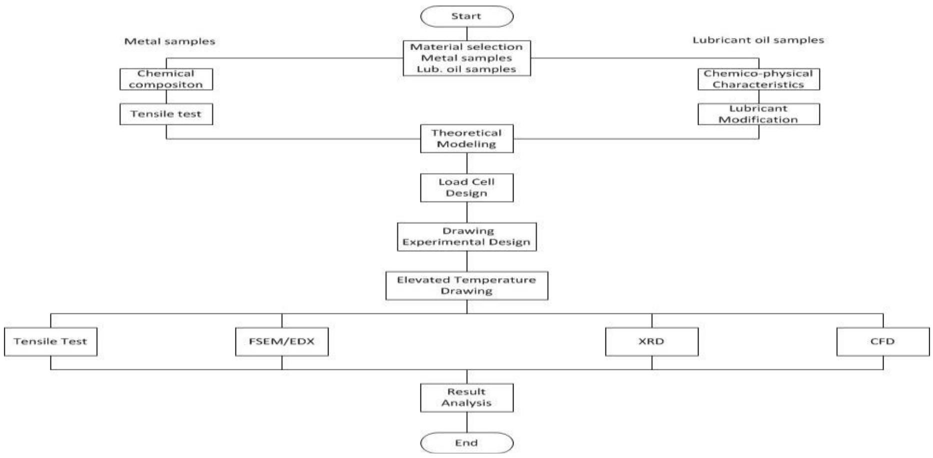

Figure 3.1 Methodology flowchart

Prior to drawing, the cut lengths of wire were pointed to ϕ4.5 mm, thoroughly cleaned and degreased and fed through the lubricant and die orifice. The drawing speed was adjusted, as was the infrared pyrometer. The initial slack was then taken up and a short length of the wire drawn. The rheostat of the induction heater was adjusted to the appropriate power position for the temperature required and switched 'on' shortly after drawing commenced. During drawing the power indicator of the induction heater, the die entrance temperature of the wire and the load reading on the AVOmeter were all recorded. On completion, all other information was recorded and the wire was labeled for future identification.Consequently, the above drawing method was scheduled as follows.

At least five draws were carried out at each temperature step for each of the lubricants used. Initially a drawing speed of 100 mm/s was decided upon. Since the drawing speed at the higher temperatures was thus limited, it was decided to carry out a number of draws at room temperature using the different lubricants and at different speeds in order to ascertain the effect this speed variation would have on the drawing load and surface finish. Several draws at different speeds ranging from 20 to 150 mm/s and using different lubricants on a die were carried out. The variation on the load for the different speeds was negligible, therefore it was decided that it was reasonable to continue on the assumption that drawing at 70 mm/s would give representative results.

Table 3.1Chemical Compositions of Mild Steel and Medium carbon steel (weight%)

Material	C	Si	Mn	S	P	Cr	Ni	Al	Cu	Mg	Ti	Zn	Fe
Mild Steel	0.05	0.01	0.04	0.014	0.016	-	-	0.033	-	-	-	-	-
Mediumcarbonsteel	0.37	0.022	0.69	0.022	0.014	0.03	0.01	-	-	-	-	-	-

Table 3.2 Chemico-physical Characteristics ofazadirachta indica and J. curcas seed oil

S/ NO	PROPERTIES	NEEM OIL	JATROPHA OIL
1	Viscosity @ 40^{0}C	185	235
2	Viscosity @ 100^{0}C	70	135
3	Viscosity Index	395	520
4	Refractive Index	1.47	1.50
5	Sulphated Ash	0.015	0.40
6	Acid Value/Total Base	1.5	3.5
7	Pour Point (^{0}C)	1.3	0.2
8	Density Kg/m^3)	1.40	150.5
9	Colour	Light Brown	Black
10	Flash Point (^{0}C)	260	275

Upper Bound Solution

In the upper bound solution, the minimum energy required to deform the metal is calculated. The material is assumed to shear as it crosses the shear surfaces at the inlet and outlet regions of the deforming zone.The assumed velocity field is shown in fig.3.2 below. The inlet and outlet shear surfaces that is Γ_1 and Γ_2 were assumed to be exponential in shape, where ρ_1 follows the equation;

$\rho_1 = \rho_0 \exp[c\,(\boldsymbol{\theta}-\alpha)]$

Where c is a variable used to minimize the draw stress, In reality, the shear surface is more complex as can be seen in the visioplasticity test patterns, but an exponential surface was cIt is assumed that under a steady flow, a particle enters the inlet shear surface Γ_1 with a uniform linear velocity $V_{1,}$ parallel to the draw axis. The velocity field in the deformation zone 2 is assumed to be directed towards the virtual apex of the die.

The equivalent strain rate $\dot{\varepsilon}$ is expressed as:

$$\dot{\bar{\epsilon}} = \frac{2}{\sqrt{3}}\,[\dot{\epsilon}^2_{\rho\rho} + \dot{\epsilon}^2_{\theta\theta} + \dot{\epsilon}^2_{\phi\phi} + 2(\dot{\gamma}^2_{\rho\theta} + \dot{\gamma}^2_{\theta\phi} + \dot{\gamma}^2_{\phi\rho})\,]$$

$$= 2V_1 \frac{\rho_0^2}{\rho^3} \exp[2c(\theta-\alpha)]\,[(\cos\theta + c\sin\theta)^2$$

$$+ \frac{1}{12}\,(3c\cos\theta + (2c^2-1)\sin\theta)^2]^{1/2}$$

The equivalent strain $\bar{\epsilon}$ is given by:

$$\bar{\epsilon} = \int_0^t \dot{\bar{\epsilon}}\, \mathrm{d}t$$

where $\mathrm{d}t = \mathrm{d}\rho/\mu_\rho$, from which

$$\bar{\epsilon} = 2 \ln \frac{\rho_1}{\rho} \left[1 + \frac{1}{12} \left(\frac{3c \cos\theta + (2c^2 - 1) \sin\theta}{\cos\theta + c \sin\theta} \right)^2 \right]^{1/2}$$

The distribution of temperature and flow stress within the deformation zone was assumed that the adiabatic conditions prevail and that both plastic and frictional work degenerate into heat.For the purpose of computation, the deformation zone is divided into (N_ρ+1) and N_θ equally spaced arcs and angles, respectively. Thus, the whole deformation zone can be identified by co-ordinates (I, J) as shown in figure 3 below.For the mild steel and medium carbon steel investigated, it was assumed that the true stress-strain curve obeys the power relationship:

$$\sigma = B\bar{\epsilon}^n$$

The opposing effects of temperature and strain rate were assumed to be related to a single parameter known as the velocity-modified temperature T_m expressed as:

$$T_m = T[1 - \kappa \ln (\dot{\bar{\epsilon}}/\dot{\bar{\epsilon}}_0)]$$

chosen to facilitate theoretical analysis.

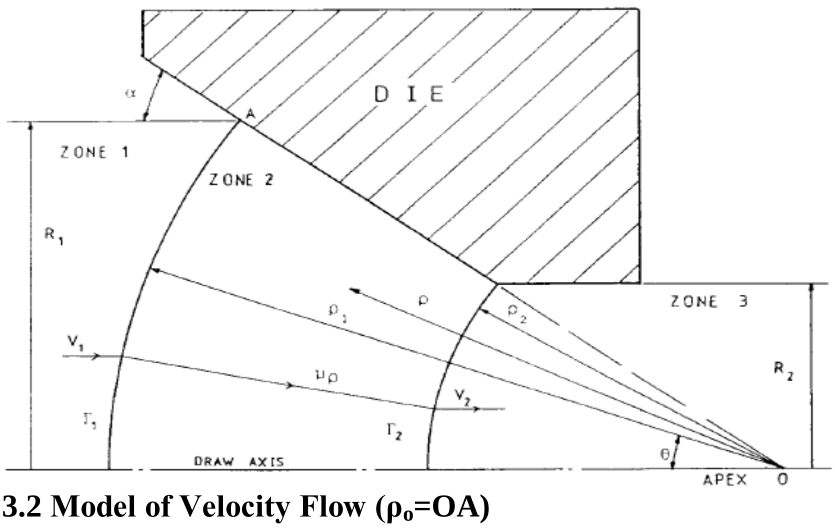

Fig. 3.2 Model of Velocity Flow (ρ_o=OA)

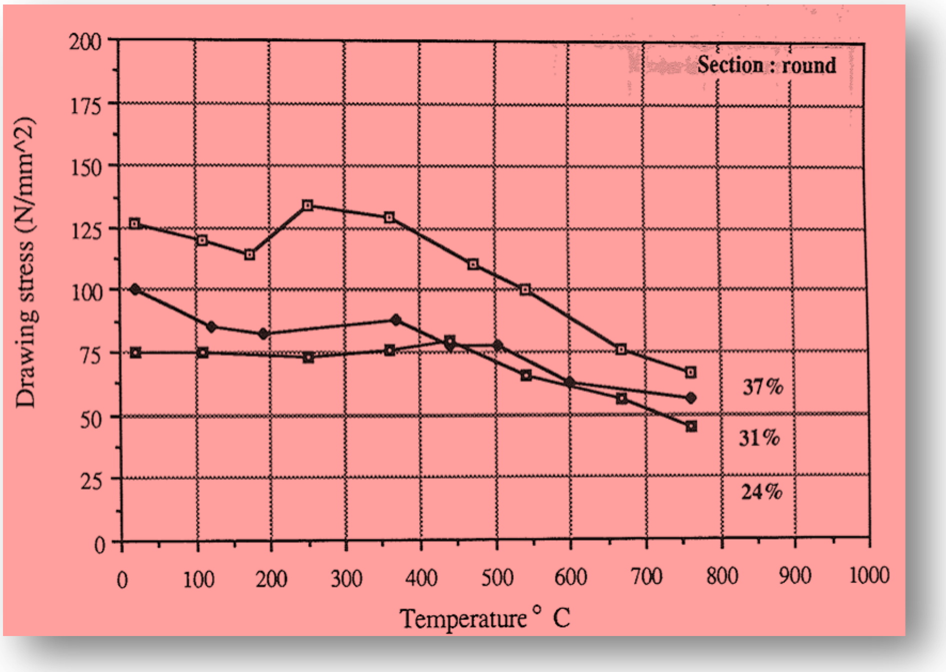

Fig 3.3. Variation of experimental drawing stress with temperature and reduction of area using Tungsten carbide dies.

III. Discussion

A basic trend of a decrease in the uniformity of the wire profile as percentage reduction increased and a singnificantly decreases high flow stress and tool force of the material was observed. The drawing process at elevated temperature successfully achieved reductions of up to 40-48% in the wire cross-sectional area by passing the drawn wire through the die without wire fracture. This was in agreement with work done by Michael and Vincent (2005) who used different die materials and lubricants in drawing wire at higher temperature, they achieved a reduction of 36-45 % in the cross-sectional area of the wire.

At temperatures greater than 550°C the drawn wire had a smooth shiny surface, indicating a more efficient lubrication. Loh and Samsone (1989), using graphite and molymdenium disulphide as a lubricant, also noticed this smooth surface effect at the temperatures in excess of 400°C. A possible explanation for the constant drawing force is that the yield stress drops due to the increase in temperature, but the coefficient of friction increases, thus cancelling out the benefit of the lower yield stress.

IV. Conclusion

A broad investigation of the mechanics of drawing at elevated temperature was successfully accomplished; this paper suggests that the mechanics of wire drawing at elevated temperatures is not very tedious from cold drawing. The effect of increasing the temperature significantly reduces the flow stress of the wire and considerably reduces the drawing force required. The reduction in flow stress brings with it major lubrication and tribology problems, which require lubricants which are efficient at the temperatures used. These lubricants are not normally used in wire drawing.Apparently, the azadirachtaindica and J. curcas seed lubricants used proved to be the most efficient at all temperatures for this research.Tungsten carbide was the most suitable die material at all temperatures.

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