Calculation of Lubricant Film Thickness in Wire Drawing Process

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الخلاصة:

يتعرض هذا البحث لدراسة وحساب سمك طبقة سائل التزييت في عملية سحب الأسلاك وعلاقتها بنسبة تخفيض المساحة (Area Reduction)، وزاوية قالب السحب (Die Angle)، وإجهاد الشد (Tensile Stress). أجريت هذه الدراسة على أسلاك النحاس المستخدمة في شركة أور العامة للصناعات الهندسية حيث يتم سحب هذه الأسلاك من قطر (8 mm) إلى أقطار مختلفة تبعا لنوع الاستعمال.
وقد تمت دراسة تأثير نسبة التخفيض على سمك طبقة سائل التزييت وذلك بأخذ خمس نسب تخفيض مختلفة وهي (75%,81.9375%,87.75%,91.734375%,94.9375%) وقد وجد أن سمك طبقة سائل التزييت يجب أن تقل كلما ازدادت نسبة التخفيض.
أما لمعرفة تأثير زاوية قالب السحب فقد أخذت ستة زوايا هي ($9^o,12^o,15^o, 20^o, 50^o, 70^o$) وقد لوحظ بأن سمك طبقة سائل التزييت تنخفض بازدياد زاوية قالب السحب لنفس نسبة التخفيض.
كذلك تمت دراسة تأثير نوع سائل التزييت على سمك طبقة سائل التزييت وذلك بأخذ ثلاث أنواع من سوائل التزييت وهي (UNOPOL CB, UNOPOL CM, UNOPOL CBF) وقد وجد أن سمك طبقة سائل التزييت تزداد بازدياد معامل اللزوجة.
لقد أظهرت المقارنة بين الحل التحليلي والنتائج المستخرجة من البرنامج المستخدم أن القيم المستخرجة جيدة ويمكن الاعتماد عليها.

Abstract:

In this work ,calculation of lubricant film thickness and its relation with area reduction, die angle, and drawing stress were studied.

A study on area reduction in wire drawing process of a copper is carried out, the lubricant film thickness usually reduced when the area reduction are increased. In order to know the effect of die angle on lubricant film thickness, three values of die angle ($9^o,12^o,15^o$) were taken. This study show that, the lubricant film thickness increase when die angle increase. Also the effect of lubricant viscosity were studied by take three types of lubricant (UNOPOL CB, UNOPOL CM, UNOPOL CBF).

A comparison between the analytical solution and the program results showed that the program produced a good results.

Introduction:

In wire drawing which is one of the oldest metal forming processes, an important part is played by the lubricant which not only improves the surface finish of the product but can also act as a heat insulation between the billet and the die, both effects tending to lengthen die life.

The lubricants selection is done by taking into account quality criteria, wire mill activity and operational efficiency, which includes the costs of operation. Moreover, these costs of operation could be higher if environmental criteria were not taken into account to choose the appropriate lubricant.

Ruiz[1] deals with the environmental assessment of some lubricants before and after the wire drawing process, A.I.Obi[2] obtained reasonable data for lubricity criteria of fatty-based oils. S.M.[5] Weygand and others develop methods for calculating the residual stresses reliably to reduce them and thereby to minimize the risk of splits.For this purpose a finite element model for the drawing process is developed and applied to study the effects of material properties and process conditions. U.S. Dixit [4] made a comprehensive investigation of the steady-state wire drawing process to study the effects of various process variables on important drawing parameters and deformation.

Wire Drawing:

Wire drawing is an operation to produce wire of various sizes within certain specific tolerances. The process involves reducing the diameter of rods or wires by passing them through a series of wire drawing dies with each successive die having smaller bore diameter than the one preceding it. The final wire size is reached as the wire passes through the last die in the series.

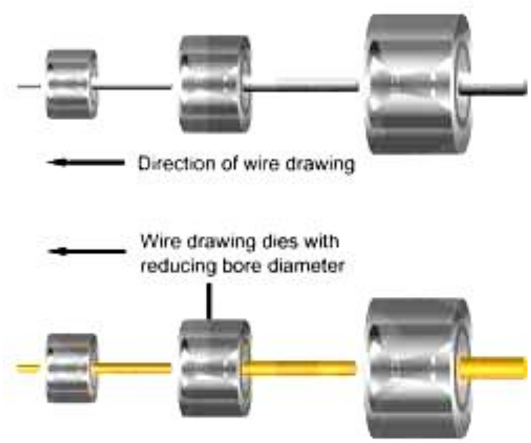
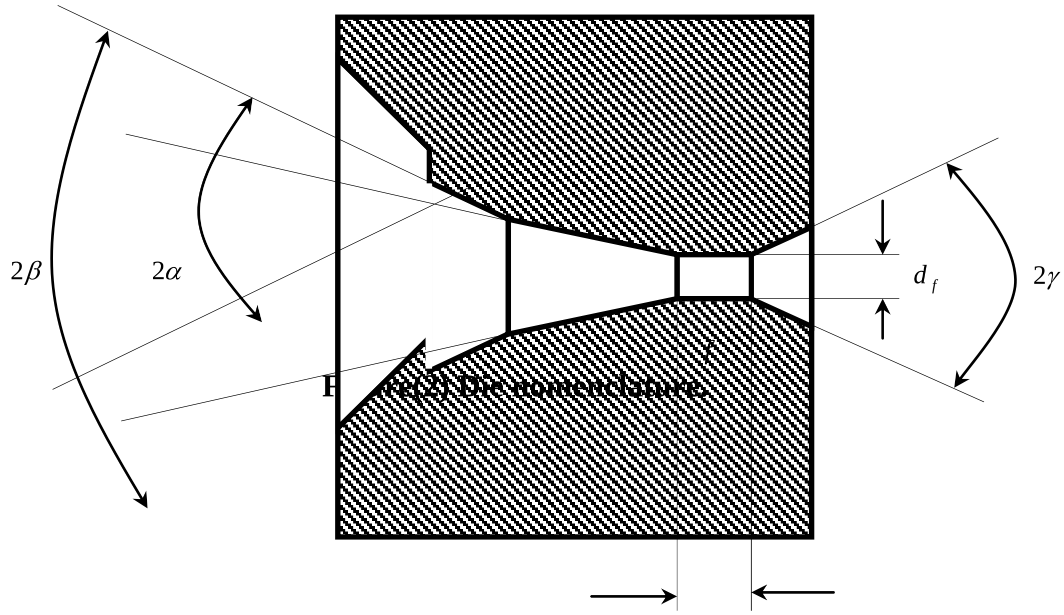


Figure (1) Example of wire drawing process, Steel and Copper.

Wire Drawing Dies:

A wire drawing die is a tool that consist of a highly polished, shaped hole through which wire is drawn to reduce its diameter. The choice of die material, viz. natural or synthetic single crystal diamond, polycrystalline diamond, carbide etc. depends on the material of the wire to be drawn and the operating parameters.



Figure(2) Die nomenclature.

During deformation, a thin film of lubricant between wire surface and die surface is essential to minimize friction, to reduce die wear, and to keep the die cool.

Avitzur[3] employed upper bound approach based on admissible velocity field to calculate the drawing stress. The expression, he obtained for drawing stress, is as follows:

$$\sigma_{xf} = \sigma_o \left\{ 2f(\alpha)\ln\left(\frac{R_o}{R_f}\right) + \frac{2}{\sqrt{3}}\left[\frac{\alpha}{\sin^2\alpha} - \cot\alpha + m_f \cot\alpha \ln\left(\frac{R_o}{R_f}\right)\right]\right\} \quad \text{.......................(1)}$$

Where

$$f(\alpha) = \frac{1}{\sin^2\alpha}\left[1 - \cos\alpha\sqrt{1 - 0.9167\sin^2\alpha} + 0.087\ln\frac{1+\sqrt{0.9167}}{\sqrt{0.9167}\cos\alpha + \sqrt{1 - 0.9167\sin^2\alpha}}\right] \quad \text{......(2)}$$

Case Study:

To explore the influence of the reduction area, die angle, and lubricant viscosity on the film thickness a systematic study was performed. The initial wire radius is 4mm, coefficient of friction is 0.15, σ_o =375 MPa. The input parameters for all 9 cases are listed in table(1) and table(2).

Table(1) Final radius ,initial velocity, and reduction area for all cases.

	R_f(mm)	V_o(m/s)	R.A(%)
1.	0.9	1.59469	94.9375
2.	1.15	2.067	91.734375
3.	1.4	2.45	87.75
4.	1.7	2.89	81.9375
5.	2	3.125	75

Table(2) Lubricant viscosity, die angle for each case.

	Lubricant	Viscosity(Pa.s)	Die angle(degree)
Case 1	UNOPOL CB	0.4	9
Case 2	UNOPOL CM	0.36	9
Case 3	UNOPOL CBF	0.296	9
Case 4	UNOPOL CB	0.4	12
Case 5	UNOPOL CM	0.36	12
Case 6	UNOPOL CBF	0.296	12
Case 7	UNOPOL CB	0.4	15
Case 8	UNOPOL CM	0.36	15
Case 9	UNOPOL CBF	0.296	15
Case 10	UNOPOL CB	0.4	20
Case 11	UNOPOL CM	0.36	20
Case 12	UNOPOL CBF	0.296	20
Case 13	UNOPOL CB	0.4	50
Case 14	UNOPOL CM	0.36	50
Case 15	UNOPOL CBF	0.296	50
Case 16	UNOPOL CB	0.4	70
Case 17	UNOPOL CM	0.36	70
Case 18	UNOPOL CBF	0.296	70

For all above cases the lubricant film thickness, and drawing stress are calculated.

Results and Discussion:

In this study the computed drawing stress and lubricant film thickness for copper rods of various reduction under UNOPOL CB, UNOPOL CM, and UNOPOL CBF are given in table (3). This results computed using a program called *wire drawing* in which computation based on Reynolds wedge effect with pressure-viscous lubricant, full-film lubrication assumed.

Table(3) Drawing stresses and lubricant film thickness for different reduction area, die angle

Die angle	R.A	UNOPOL CB Drawing stress(MPa)	UNOPOL CB Film thickness(µm)	UNOPOL CM Drawing stress(MPa)	UNOPOL CM Film thickness(µm)	UNOPOL CBF Drawing stress(MPa)	UNOPOL CBF Film thickness(µm)
9	94.9375	1747.7534	0.191741	1747.7534	0.141889	1747.7534	0.172567
	91.734375	1481.0957	0.1973682	1481.0957	0.1460524	1481.0957	0.177631
	87.75	1247.3877	0.2022901	1247.3877	0.149694	1247.3877	0.182061
	81.9375	1033.2988	0.2107939	1033.2988	0.1559875	1033.2988	0.18971
	75	844.40128	0.2105902	844.40128	0.155836	844.40128	0.18953
12	94.9375	1665.9436	0.149399	1665.9436	0.134459	1665.9436	0.110555
	91.734375	1385.8157	0.155239	1385.8157	0.139714	1385.8157	0.114876
	87.75	1183.9649	0.1571182	1183.9649	0.141406	1183.9649	0.116267
	81.9375	981.3	0.1632056	981.3	0.146885	981.3	0.120772
	75	802.918	0.1626724	802.918	0.146405	802.918	0.120378
15	94.9375	1579.6365	0.124746	1579.6365	0.112272	1579.6365	0.0923126
	91.734375	1333.2721	0.127909	1333.2721	0.115118	1333.2721	0.0946527
	87.75	1138.6855	0.129239	1138.6855	0.1163154	1138.6855	0.0956371
	81.9375	944.852	0.133934	944.852	0.1205409	944.852	0.0991114
	75	773.2224	0.133381	773.2224	0.1200429	773.2224	0.0987019
20	94.9375	1498.326	0.0978321	1498.326	0.088048	1498.326	0.072395
	91.734375	1272.548	0.0996165	1272.548	0.089654	1272.548	0.073716
	87.75	1091.922	0.1001867	1091.922	0.090168	1091.922	0.074138
	81.9375	902.5512	0.1039526	902.5512	0.093557	902.5512	0.076924
	75	752.3807	0.1025705	752.3807	0.0923135	752.3807	0.075902
50	94.9375	1509.8128	0.03996	1509.8128	0.035964	1509.8128	0.029571
	91.734375	1308.2147	0.040533	1308.2147	0.03648	1308.2147	0.029994
	87.75	1145.932	0.040728	1145.932	0.036655	1145.932	0.030138

		2		2		2	
	81.9375	988.1524	0.041957	988.1524	0.037762	988.1524	0.031048
	75	854.6338 1	0.041443	854.6338 1	0.037299	854.6338 1	0.030668
	94.9375	1670.302	0.0270619	1670.302	0.024355	1670.302	0.020025
	91.7343 75	1466.412 4	0.027608	1466.412 4	0.024847	1466.412 4	0.0204302
70	87.75	1303.863 9	0.027894	1303.863 9	0.025105	1303.863 9	0.020642
	81.9375	1145.071 3	0.0289395	1145.071 3	0.026045	1145.071 3	0.021415
	75	1014.539 1	0.028705	1014.539 1	0.025835	1014.539 1	0.0212422

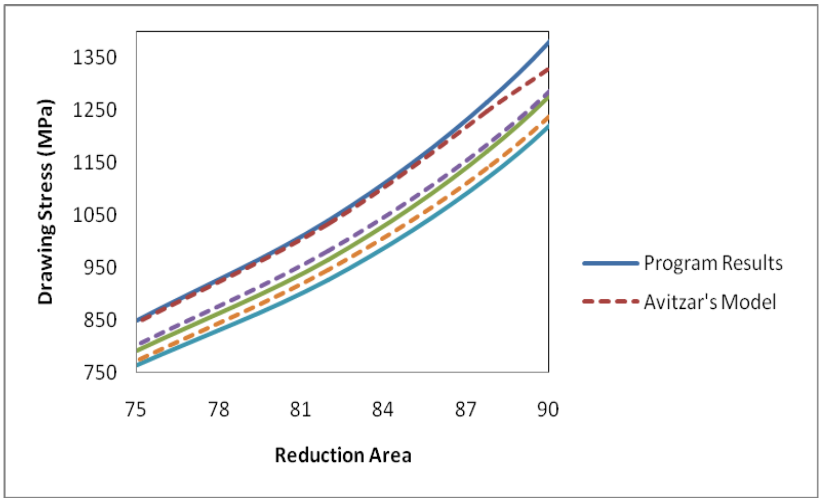
In order to verify the validity of the program results a comparison of the drawing stress obtained from the program and Avitzur's model are listed in table(4) and figure(3). It is founded that the program produced good results.

Table(4) Comparison of the analytical and program results.

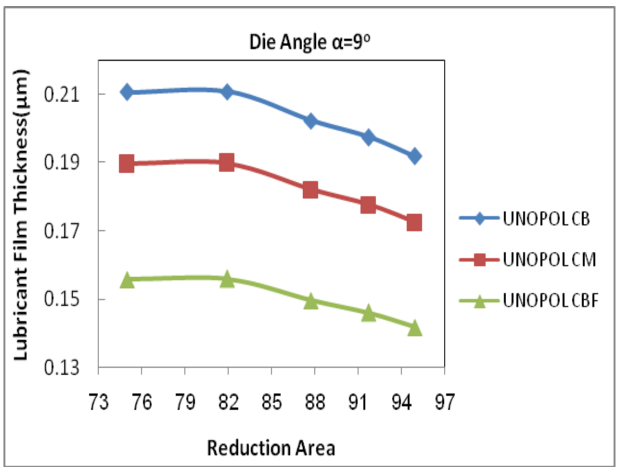
		Drawing stress(MPa)	
Die angle(degree)	R.A(%)	Avitzur's model	Program result
9	75	849.8765664	844.40128
15	87.75	1119.267882	1138.6855

In wire drawing process the lubricant film thickness are calculated at different reduction area and presented in figures (4),(5),(6). It should be noted that the lubricant film thickness decreased with increasing reduction area and die angle under the same kind of lubricant.

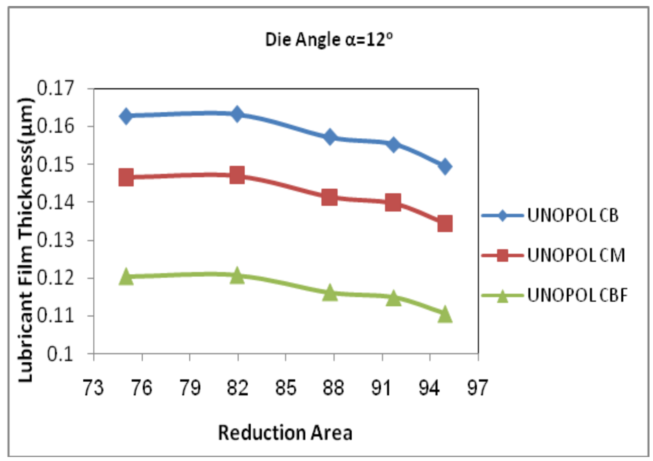
Figures (7),(8) shows the effect of reduction area on drawing stress at different die angle. When the reduction area increases the drawing stress increases also, when the die angle is very small, the length of contact between the wire and die is high, which increases the friction force, resulting in high drawing stress. When the die angle is too large , then again the drawing stress is high, because of the large distortion. The die angle at which the drawing stress takes a minimum value is called optimum die angle, in this work the optimum die angle between 20o and 30o as illustrated in figure (8). Figure (10) shows the effect of lubricant film thickness on the drawing stress; film thickness decreases the drawing stress increase; thin lubricant films exhibit a greater resistance to shear and the frictional force therefore increased so the drawing stress increases.



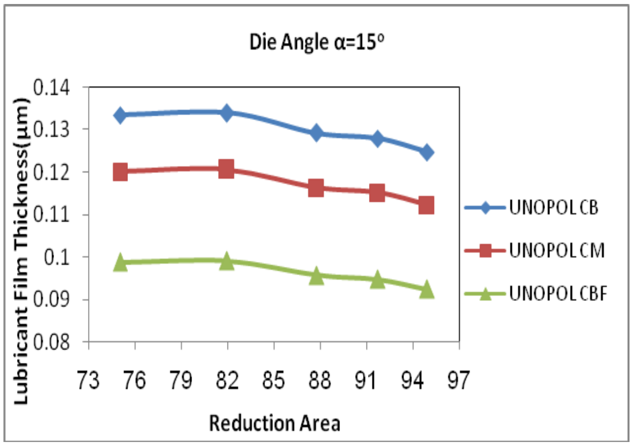
Figure(3) Comparesion between Avitzur's model and program results



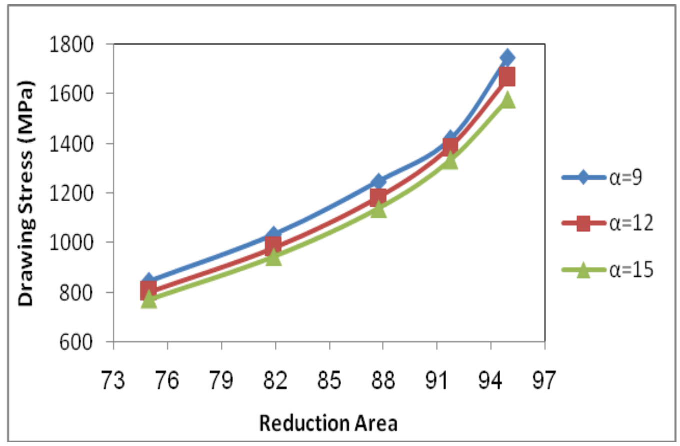
Figure(4) Variation of lubricant film thickness with reduction area for different lubricants, die angle $\alpha=9^o$



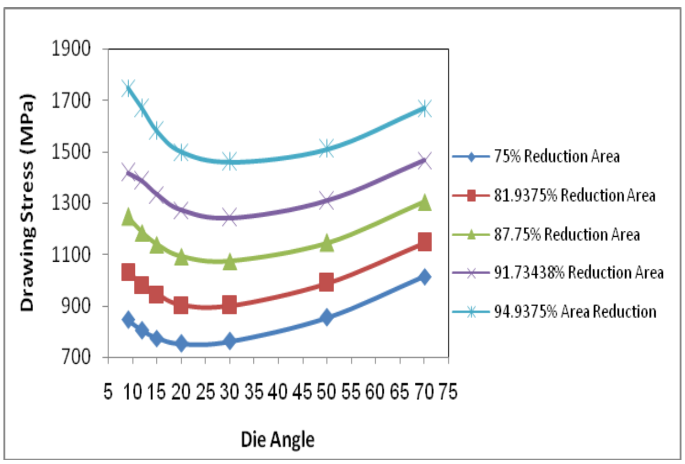
Figure(5) Variation of lubricant film thickness with reduction area for different lubricants, die angle $\alpha=12^o$



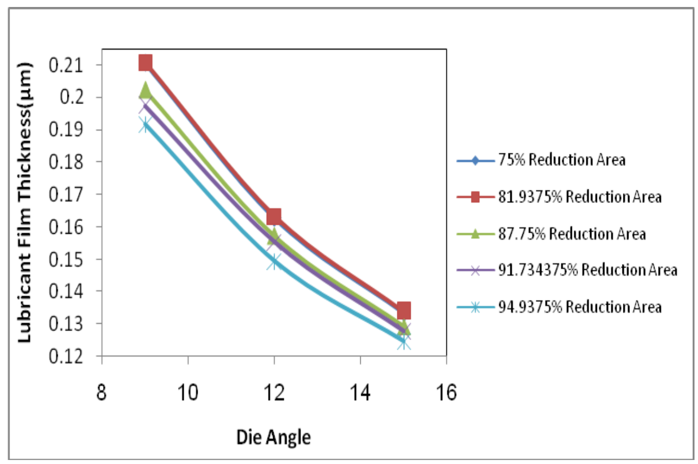
Figure(6) Variation of lubricant film thickness with reduction area for different lubricants, die angle $\alpha=15^o$



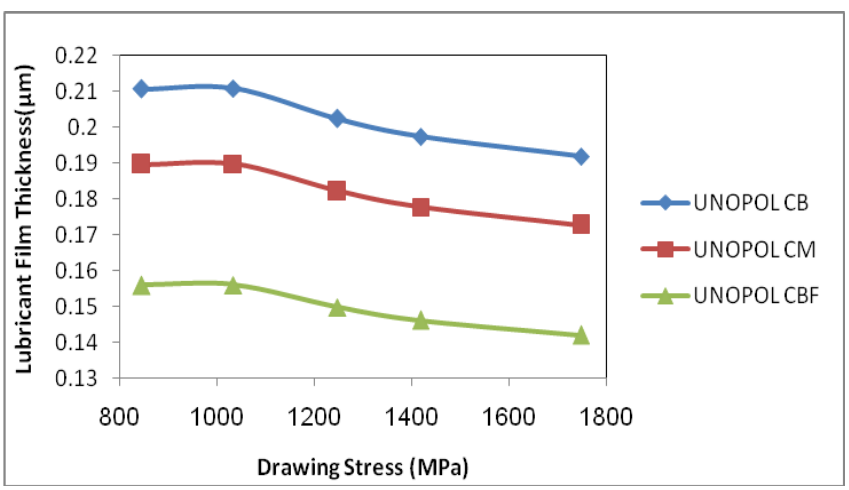
Figure(7) Variation of drawing stress with reduction area for different die angle



Figure(8) Variation of drawing stress with die angle for different reduction area



Figure(9) Variation of lubricant film thickness with die angle for different reduction area



Figure(10) Variation of lubricant film thickness with drawing stress for different lubricants

Conclusions:

For this study the following conclusions can be given:

- **When the area reduction increases the lubricant film thickness decreases and the drawing stress increase.**
- **When the die angle is too large , then the drawing stress is high because of the large distortion.**
- **the optimum die angle is between 20^o and 30^o**
- **In order to consider the high loading involved in wire drawing process a lubricant has to be selected which will not shear too easily and allow rupture and failure a situation most probable with high viscosity lubricants.**

Nomenclature:

R_o initial radius
R_f final radius
V_o initial drawing speed
V_f final drawing speed
α die angle
β entrance angle
γ back relief angle
f bearing length
σ_{xf} drawing stress
σ_o flow stress

References:

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