The effect of die shape on Hardness of copper in wire drawing process.

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Abstract :

One of the most important factors that affect the hardness of formed products is forming tool design(drawing die profile). Die profile shape with other factors like reduction of area, forming temperature , friction... etc. Will produce a specific deformation mode that characterizes deformed metal by drawing process. This will have a direct effect on hardness of the drawn product .This was carried out by studying the final mechanical properties of the drawn products through dies with theoretical concepts(UCRHS, ACRHS , DCRHS , CMSR) and other with industrial concepts taper die ($\alpha = 12^{\circ}$)
All at fixed reduction in area of 64% .
The material used in this research is commercial pure copper . the drawing process was carried out at room temperature.
Obtained results show that drawing die(CMSR) is the most efficient die design, at the same time, design of taper die ($\alpha = 12^{\circ}$) shows the lowest efficiency as compared with others.
See definition of symbols at the end of research .

ألخلاصه :

من اهم العوامل المؤثره على الصلادة للمنتجات المشكله على البارد هو تصميم الة التشكيل (المقطع الجانبي لقالب السحب) حيث ان شكل المقطع الجانبي للقالب بالاضافه الى عوامل اخرى مثل التخصر بالمساحه ودرجة حرارة التشكيل والاحتكاك ....الخ سوف تنتج نمط تشوه خاص له تاثير فعال على مواصفات الماده المشكله بعملية السحب . وبذلك سوف يكون التاثير مباشر على صلادة المنتج المسحوب.
لقد طبق هذا بدراسة الخواص الميكانيكية النهائيه للمنتوجات المسحوبه خلال قوالب مبنيه على اساس مفاهيم نظريه (UCRHS, ACRHS , DCRHS , CMSR) واخرى على اساس مفهوم صناعي($\alpha = 12^{\circ}$)
وجميع هذه القوالب لها تخصر ثابت في المساحه 64%
المعدن المستخدم هو النحاس النقي التجاري وقد نفذت عملية السحب في درجة حرارة الغرفه . لقد اظهرت التجارب التي تم الحصول عليها بان القالب نوع (CMSR) اكثر كفاءة في التصميم من جميع القوالب المصممه . في نفس الوقت تبين ان القالب المصمم على اساس صناعي ($\alpha = 12^{\circ}$) قد اظهر اقل كفاءة عند مقارنته بالقوالب الاخرى .
انظر تعريف الرموز في نهاية البحث .

1-Introduction:-

Drawing operations involve pulling metal through a die by means of a tensile force applied to the exit of the die. Most of the plastic flow is caused by compression force which arises from the reaction of the metal with die.[l] which is called die pressure.
The work hardening characteristic can be used to get workpieces whose mechanical properties are higher than them for the intial material. The work- hardening behavior is also interesting from an economical view point since cheaper material can be drawn or extruded to get the higher mechanical properties. [2]. The cross section through a typical conical drawing die is shown in fig (1-1) . The entrance angle of the die is made large enough to allow room for the lubricant that adheres to the die.

The proach angle is the section of the die where actual reduction in diameter occurs. The bearing surface serves to guide the rod or wire as it exits from the die.
For coarse wire a single bull block is used, but for fine wire a long number of draw blocks are required. with the wire passing through a number of die until it is reduced to its final size in one continuous operation. [3] To obtain good deformation in a controlled manner, the drawing tool or

drawing die, must have an appropriate special profile, which in general, consists of four different important parts, shown in fig .(1-1) [4]

A-Entrance (lubricating Zone)
B-Approach (drawing Zone)
C-Cylindrical bearing or gauging zone.
D-Exit relive.

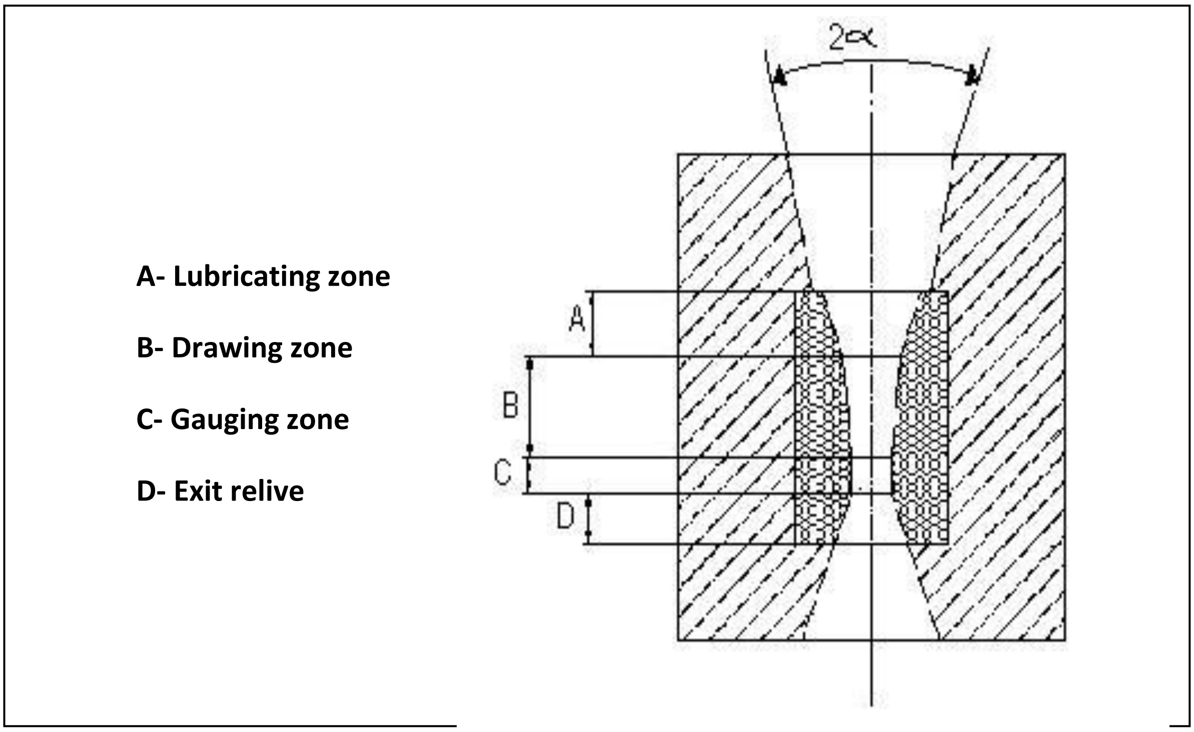


Fig.(1-1) Detai

2-Theoretical Concepts&Considerations

2-1 Work formula for the wire drawing:

$$W_1 = F_1 L_1 \quad \text{.......} (2-1)\ [4]$$

$$F = A_1 \bar{Y} Ln \frac{A_\circ}{A_1} \quad \text{.......} (2-2)$$

$$r = 1 - \frac{A_1}{A_\circ} \quad \text{.......} (2-3)$$

$$\sigma = \frac{F}{A_1} = \bar{Y}\, Ln \frac{1}{1-r} \quad \text{.......} (2-4)$$

2- 2 Theoretical principle and consideration in die design:

Homogeneous strain is very necessary to complete the forming process which is directly related Non homogenous strain or redundant strain represents internal shearing deformation, Which is directly affected by shape of die [5] or the shape of deformation zero .

$$d\varepsilon_t = \sqrt{\frac{2}{3}} * (d\varepsilon_{i,j} . d\varepsilon_{i,j})^{\frac{1}{2}} \quad \text{.......} (2-5)$$

$$d\varepsilon_x + d\varepsilon_y + d\varepsilon_z = 0 \quad \text{.......} (2-6)\ [4]$$

or

$$\varepsilon_x + \varepsilon_y + \varepsilon_z = 0$$

$$\therefore \varepsilon_H = \sqrt{\frac{2}{3}} * (\varepsilon_x^2 + \varepsilon_y^2 + \varepsilon_z^2)^{\frac{1}{2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2-7)$$

Where:

ε_x = longitudinal strain

ε_y = radial strain

ε_z = circumferential strain

$$\varepsilon_{Hn} = L_n(Z_n) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2-8)$$

Where : Z_n is a function which is limited by engineering dimensions of specimen .

$$\frac{Z_n}{Z_{n-n}} = (Z_1)^{S^{n-1}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2-9)$$

Where : Z_n value of (Z) at section (n) of pass length.

$$Z_n = \left(\frac{R_\circ}{R_n}\right)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2-10)$$

At $n = 1$

$$Z = \left(\frac{R_\circ}{R_1}\right)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2-11)$$

Where :

$R_\circ$ = Original radius of specimen

R_n = Radius of specimen at any section

R_1 =Final radius of specimen

$$Z_n = (Z_1)^{s^{(n-1)}} * Z_{n-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2-12)$$

$$\therefore Z_n = (Z_1)^k, K = S^{n-1} + S^{n-2} + \ldots\ldots\ldots. S + 1 \ldots\ldots\ldots\ldots\ldots\ldots (2-13)$$

Where:

S=deformation rate

Uniform deformation (S=1)

Accelerated deformation (S>1)

Decelerated deformation (s<1)

$$(\bar{\dot{\varepsilon}}_H)_x = \frac{1}{x}\left(\frac{R_\circ^2}{R_x^2} - 1\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2-14)$$

Where $(\bar{\dot{\varepsilon}}_H)$mean homogeneous strain rate as function of distance

<u>2-3 the effect of drawing die shape on hardness distribution at the product longitudinal cross section:</u>

The external limitation assumed by die geometrical shape will be to generate of internal shearing deformation in specimen (redundant deformation) which added to required deformation to change Specime shape as shown in fig (2-1) in level (l) of specimen which is near to the external surface, we notice that element of plane will subject to appointed mode of deformation . The element moves at beginning towards the die in parallel direction to x - axis, but when the element start to entry to die, then the element will forced to move in parallel direction of die surface it will generate component for element velocity in y- axis, this cause internal shearing deformation in that element when the element is leave the die then the element will subject to another internal shearing deformation to move in X- direction .

From the elements in plane (2) horizontal identity axis we notice that the elements in this region do not subject for any internal shear deformation, also will not subject any redundant deformation. Appear of which presentation or progress that different element in formation zone in die will subject to different degrees of redundant shearing deformation [the value of it between zero in plane (2) to maximum value in die surface plane[1]

By another meaning, that the hardness values of specimen will be variable from product surface to product center , then the hardness value in specimen surface will be greater than it value in centre of specimen [6].Fig(2-2)shown the distortion of an element of strips as it passes through a drawing die. The types of used dies in this research are shown in fig . (2-3)

(2-4) Hardness:

The hardness of metal is difficult as difficult as a distinct properties because it is closely associated with metal structure, composition, & other mechanical properties . consequently , a number of different kinds of hardness have come to be recognized . those test which measure resistance to indentation will be consider here .

Resistance to indentation is measured by applying an indenter of a particular shape to the subject metal under suitable static load .

The hardness measured in this way is assigned a numerical value based eigher on the contact area of indenter & metal , the projected area of the recovered indentation , or the depth of the recovered indentation . Test in common use are Brinell , Rekwell , Vickers , & Monotron . At Veckers hardness test a load from (5-500)kg is applied through a square based pyramid (136°) & remove automatically by a weight cam mechanism .

The load is chosen in relation to the hardness & thickness of the part .

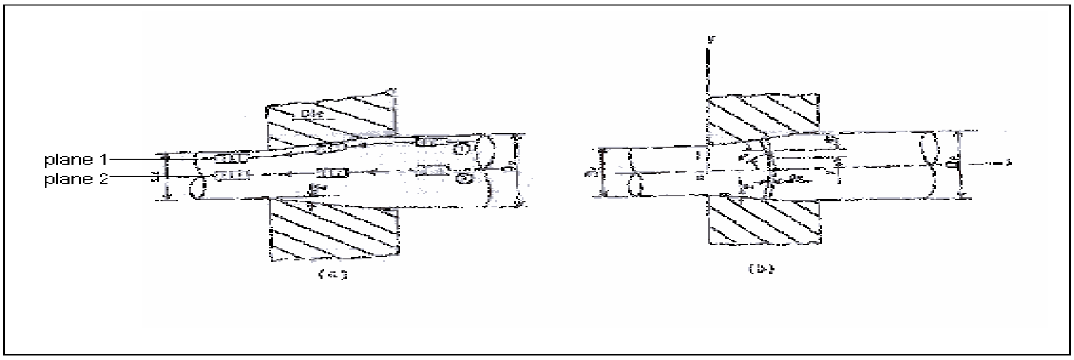
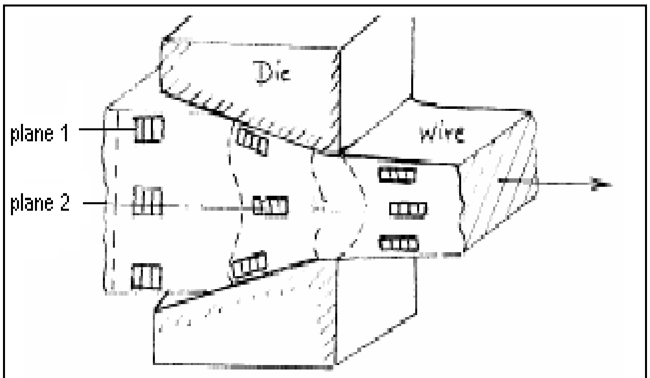
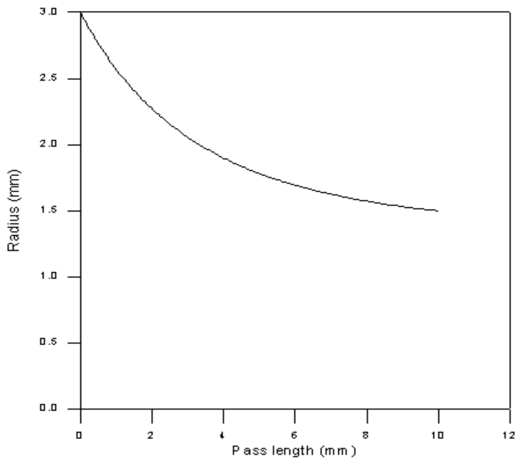


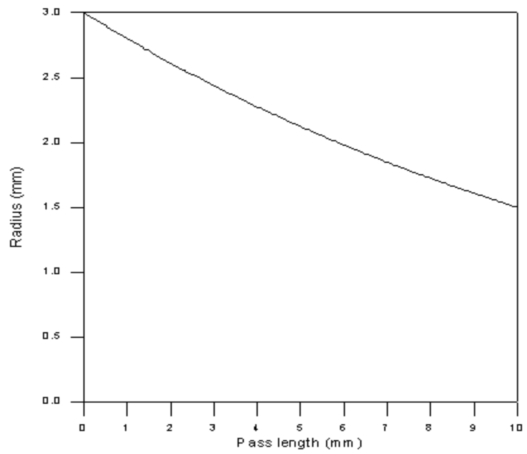
Fig.(2-1)(a) Deformation for element when passes through conical die
(b) Deformation for element lie at distance y of (x-axis) [2]



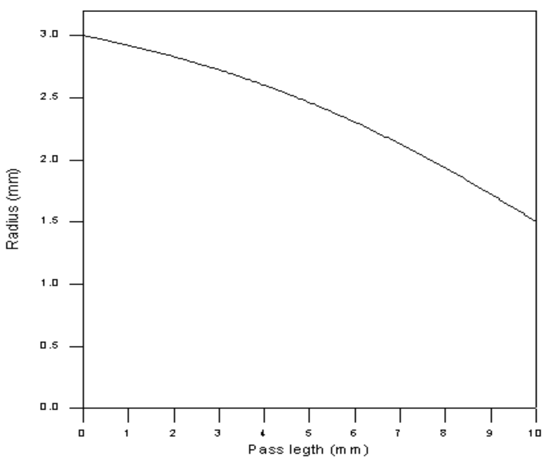
Fig(2-2)S… e 1 & plane 2 [5]



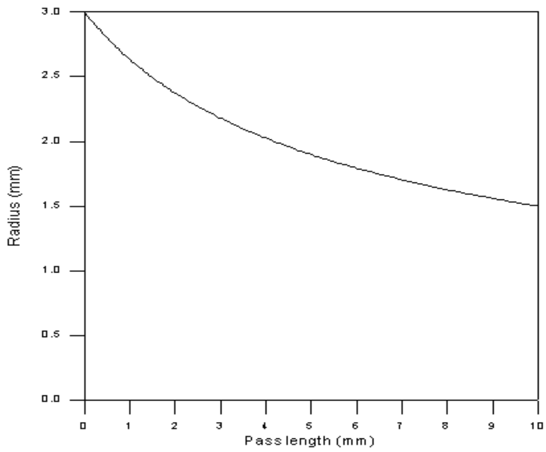
DCRHS



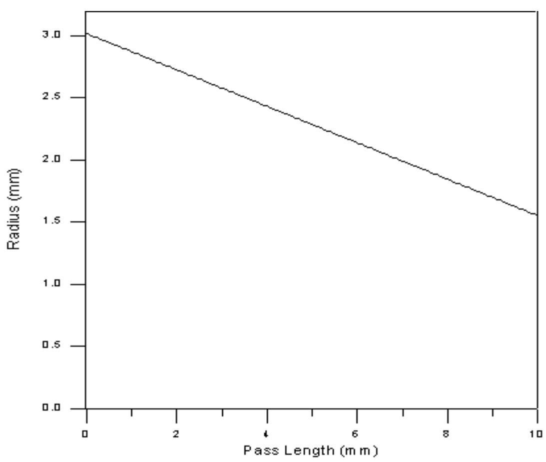
UCRHS



ACRHS



CMSR



$\alpha = 12^\circ$

Fig.(2 -3) Types of Dies

3- Experimental Procedures

3-1 Wire drawing Machines

Wire drawing machine is constructed as a single block unit (one stage) . This machine is used for the layer sizes. But for finer wire, the drawing tool may be constructed from an assembly of bocks to form the shape of product (multiple stages) . Each stage consists of electrical working unit, wire drawing die found in lubricant box which contain soap powder to cover the wire and drawing pulley as shown in fig.(3-1)

3-2 Utilized Dies

Dependence on theoretical conceptions mentioned while doing the required calculations, we can obtain the required geometry shapes of drawing die. The purpose of this different design is to make a comparison between the efficiency of drawing die which depends in design on theoretical conceptions (CRHS & CMSR) and dies which depend in design on industrial conception in design

typer die ($\alpha = 12^{\circ}$)

Utilized dies were manufactured from steel, according to description. ISO 340 sandrik , Nib to Grad(G20)

This dies were manufactured by using (CNC) machine to obtain a geometrical shape for forming pass.

To raise mechanical properties of used dies, the dies were put in a electrical furnace type (carbolated - PID,max $1200 c^{\circ}$) at temperature 1050 c° for one hour. After that the dies were taken out of the furnace to cool out in air, also tempering process was carried out in ($450 c^{\circ}$) for one hour.

Fig .(3-2) represents the types of dies (DCRHS, UCRHS , ACRHS , CMSR, taper die ($\alpha = 12^{\circ}$) which were used in experement .

3-3 Samples preparation

The choosing of metal was pure copper because this material is easy in the drawing process which it is in annealed state, where the ductility is very high in addition to equivalent strain method metal

has the capability of hardening and strain with clear cut image.

The wire is drawn by wire drawing machine as shown in fig. (3-1)

where wire end rolled to enter the die the wire is reduced from (5mm) to (3mm) diameter though one die.

Samples were prepared for hardness test using support powder with hardening liquid (acrylic acid). The specimen is put in special die for this purpose and put the support pasta was put on specimen in die.

After one hour, the specimen was taken out from the die and prepared to grinding and polishing.

Rotary pregrinder device was used for grinding & polished the specimen , Grinding papers used in grinding are (250-500-1000-1200). After that polishing cloth was used .

3-4 wire drawing process:

Wire was made under cold drawing hot - rolled wire rod through one die, to decrease its size and increase the mechanical properties.

The wire (6mm in diameter) is rolled from a single billet and cleaned in acid bath to remove scales, rust and coating .

A single - draft process was used. In this method a coil is placed on a reel or a frame and end of wire pointed so that it will enter the die. The end is grasped by tongs on a draw - bench and pulled through to such length around a drawing block or reel (the speed 80 m/m). The lubricant used in this process was soap powder

3- 5 Micro hardness test (Vickers) :

To perform micro hardness test the micro hardness test device was used type (universal camera microscope, Me F2 , serial No .363753).

The load (500 gm) to time (10 sec) are used for each micro hardness test.

Micro hardness test region of product longitudinal section is shown in Fig(3-2)
The distance between trace & another is taken (2.5)diameter of the first frace as in Fig(3-3)

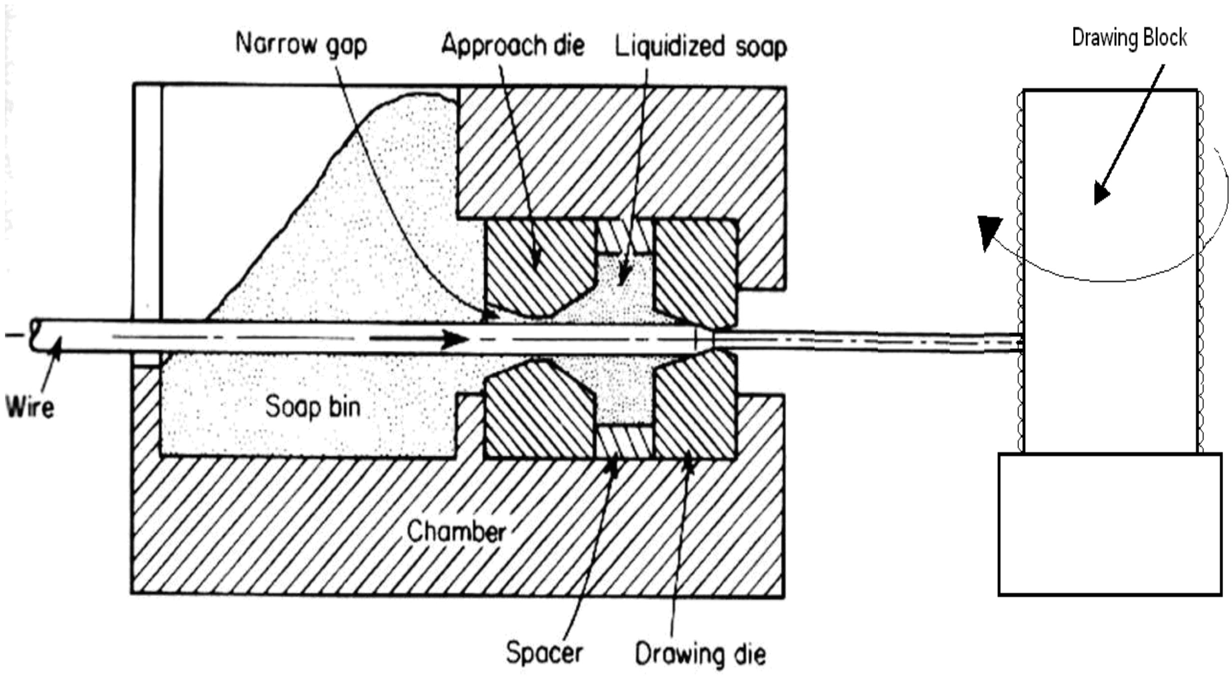


Fig.(3-1) Hydrodynamic lubrication with dray soap

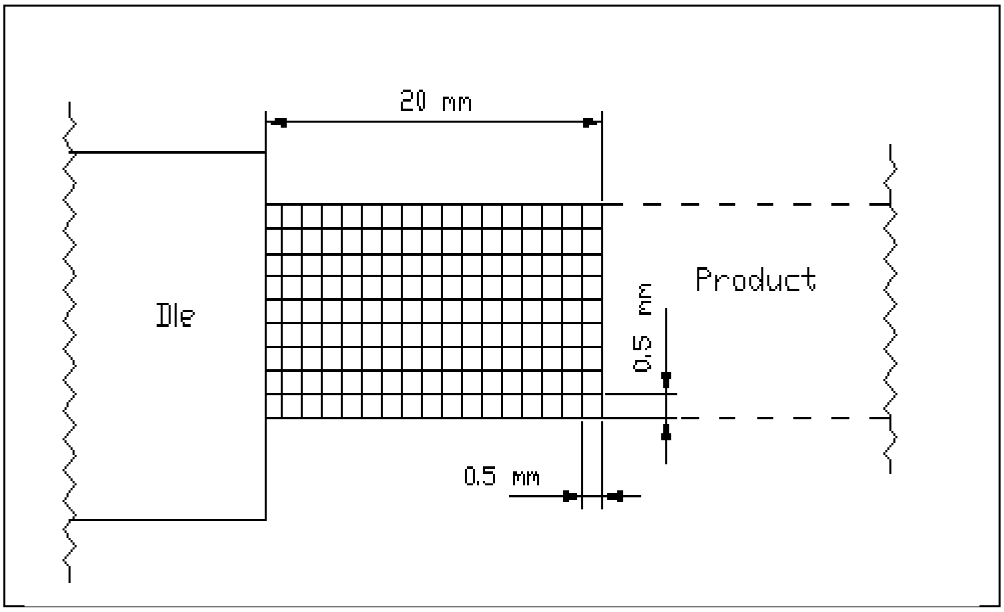
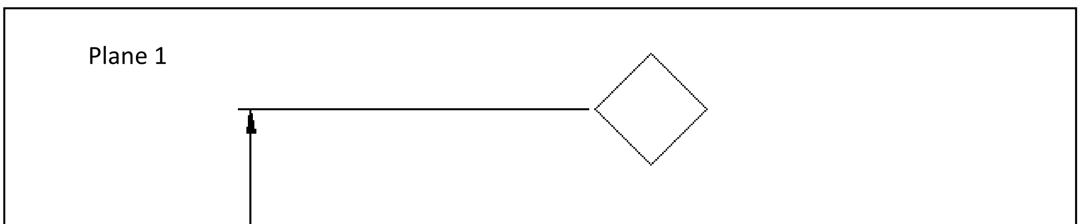


Fig.(3-2)Micro hardness test region (product longitudinal section)



Plane 2

D=(d1+d2)/2

X=2.5 D

Fig.(3-3) the dividing method between one trace & another for micro-hardness test (Vickers)

4 -Results and Discussion:

4-1- Introduction:

The reduction of area was constant for all dies which is equal to (64%) .

Micro hardness test (Vickers) was used to perform of survey process for specimens longitudinal cross section, because the smallness of the cross section surface require a survey it , as shown in fig ness (4-1),(4-2),(4-3),(4-4),(4-5)

4-2 Distribution modes of micro hardness values in longitudinal cross- Section of formed specimens:

We used a longitudinal cross - section survey method for specimen by using micro hardness test (Vickers) in the same region from which the Specimens were taken.

By noticing figures (4-1),(4-2),(4-3),(4-4),(4-5).

We find that the differences is very clear in distribution modes of micro hardness values in longitudinal cross sections of the specimens.

This differences in distribution modes is due to the difference in design of dies shapes in this research.

Fig (4-4) represents the distribution mode of micro hardness values in the longitudinal cross section of the specimen obtained by using drawing die (CMSR). We notice the tendency to homogeneity in distribution mode of micro hardness values, in addition to little difference between the micro hardness values in the region of specimen surface which is near to die limitatations with micro hardness values in the region of symmetry axis of the specimen which anayform die limitations.

As the micro hardness values tend of arrive to micro hardness value of pure copper in annealed state (50HV) this indicates a decrease in the level of the redundant shear.

Fig (4-5) shown the different in the hardness values in the longitudinal cross section of speciment obtained by using drawing die (($\alpha = 12^{\circ}$)) as compared with the hardness values curves of pure copper in annealed state this indicate to redundant shearing levels which is generated in forming specimen by drawing die type ($\alpha = 12^{\circ}$) , which is higher then redundant shearing levels generated by other type of drawing die .

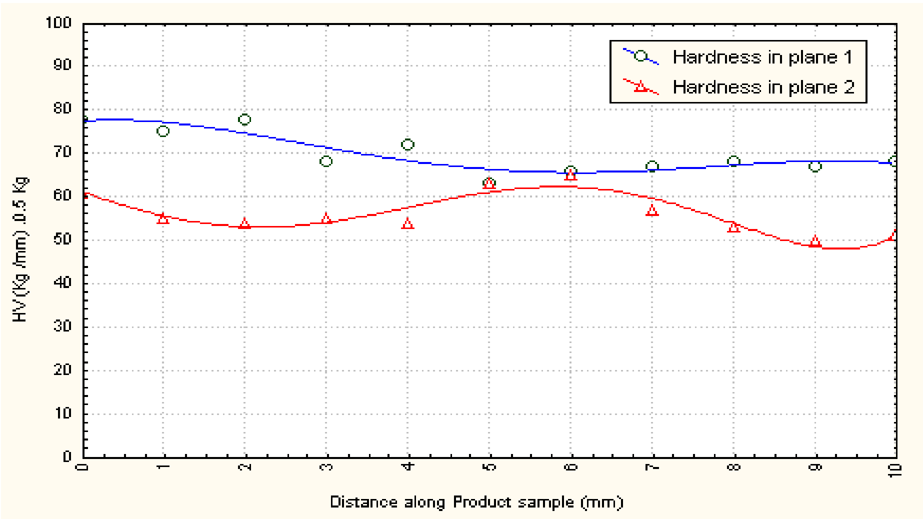
All researches related to study & design of conical dies , curved dies & stream lined dies showed , that stream lined & curved dies have more efficient than conical dies .

Fig (3-2)Micro hardness test region (product longitudinal section)

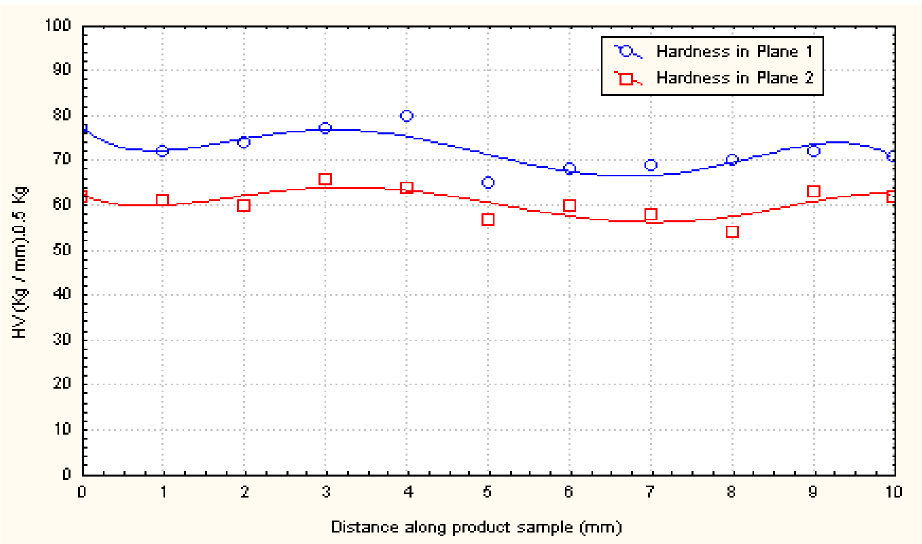
Blazynski , T.Z presented study for dies design by depending on theoretical conceptions , this conceptions are called (constancy of the ratio of the successive generalized homogeneous strain increment CRHS) & (constancy of the main strain rate CMSR) & made comparison between these dies. Then he called to know , that designed dies in theoretical base reduce the values of redundant strain more then designed dies in industrial base (taper dies) . At the same time the researcher called know ,that the die type CMSR more efficiency from all.

Also the researcher Avitzur ,B. presented study about limit analysis of flow through conical converging dies & metal forming . He made comparison between the conical dies & designed dies in theoretical base , he found , that material flow in dies type CRHS faster then in conical dies .

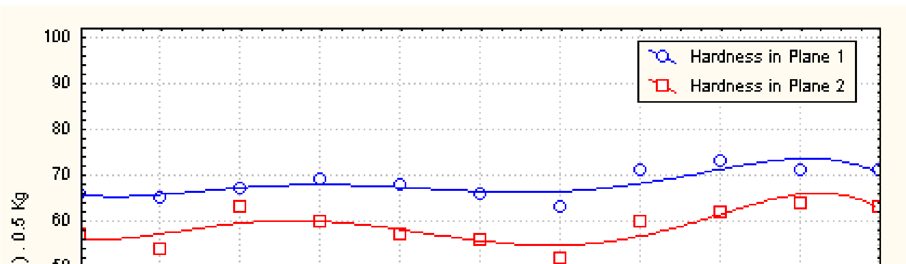
Ismael . A.A study the effect of the dies shape on mechanical properties of copper in wire drawing process . the researcher study tensile & hardness of product for all dies , he found the die type CMSR more effeciency of all.



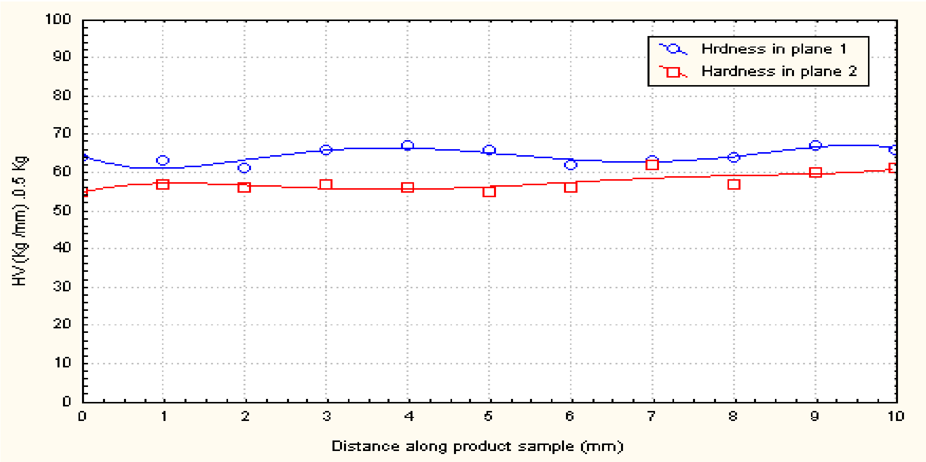
Fig(4-1)Die Type DCRHS



Fig(4-2) Die Type UCRHS



Fig(4-3)Die Type ACRHS



Fig(4-4)Die Type CMSR

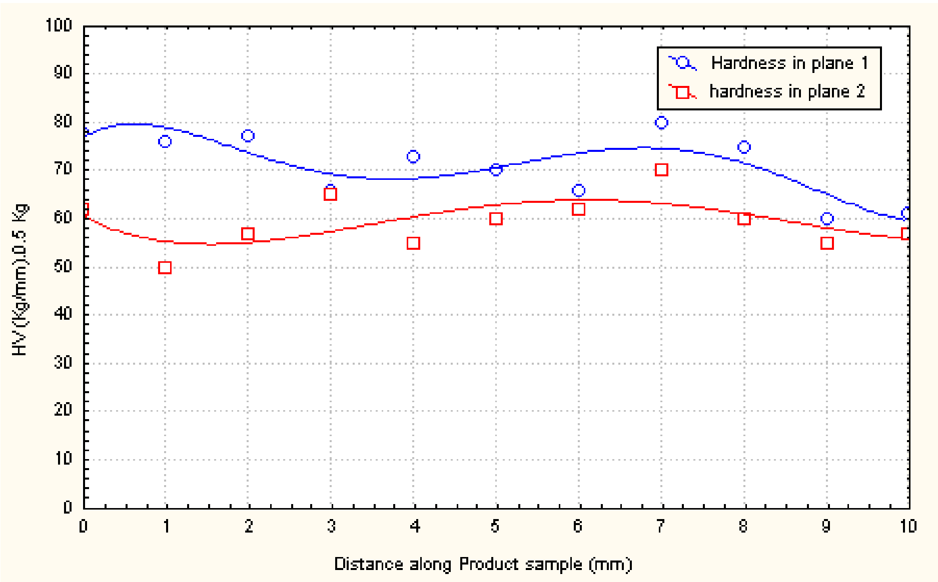


Fig (4-5) Die type $\alpha = 12^{\circ}$

Conclusion

1- Good agreement between the results relating to the survey of longitudinal cross section of the specimens were subjected to strain hardening (drawing process) and the result which obtained by using equivalent strain method.

2- Through comparison between designed dies depending on theoretical conceptions in designed, we find that dies (DCRHS, UCRHS , ACRHS) are identical in efficiency.
3- Through comparison between the designed dies depending on theoretical conceptions and the designed dies depending on industrial concepts.

It was found that die (CMSR) has higher efficiency and (taper die α = 12°) Has lower efficiency.

Table of symbols

No.	Symbol	Definition	Unit
1	$A_{\circ}$, A_1	Original & final area respectively	$(mm)^2$
2	ACRHS	Accelerated constancy of the ratio of successive generalize homogeneous strain increments	-
3	CMSR	Constancy of mean strain rate	-
4	DCRHS	Decelerated constancy of the rate of successive homogeneous strain increments	-
5	k	constant	-
6	n	Strain hardening exponent	-
7	r	Reduction of area	-
8	s	Deformation rate	-
9	UCRHS	Uniform constancy of the ratio of successive generalize homogeneous strain increments	-
10	W	Work done	(joule)
11	$(\bar{\dot{\varepsilon}}_H)$	Mean strain rate at section (h) along the pass length	1/s
12	ε_t	Total true strain	
13	ε_x	Longitudinal strain	
14	ε_y	Radial strain	
15	ε_z	Circumferential strain	
16	ε_H	Homogeneous strain	
17	σ	True strain	(Mpa)
18	α	Semi cone angle	(degree)

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