Effect of the Rolling Direction and Draft on Some of the Mechanical Properties for the Medium Carbon Steel

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Abstract: ***The aim of this research is to investigate the effect of rolling direction (0, 30, 60 and 90)o and reducing ratio of plate thickness on some mechanical properties (tensile strength, hardness, average flow stress and microstructure) of cold working for medium carbon steel (DIN CK 45). It has been found from experimental results, the direction of rolling process in range of (0< Ө < 90o) (where Ө is the entry angle of specimen relative to rolls axises) takes a convex curve shape, where the average flow stress and hardness is less than that found in vertical and horizontal direction of entry specimen. Also it is found that there is a proportional relation between the angle of rolling and the tensile stress Theoretically and practically, so the direction of rolling affects on the microstructure without any change in the proportions of the components phases of medium carbon steel which was investigated.***

Keywords: Rolling direction, Draft, tensile stress, hardness, MCS

1. Introduction

Forming processes are the processes by which we obtain of the required shape of the production through applying of plastic deformation process on the metal [1], Some of them by using temperature which is called (hot forming) and the others by no using the temperature which called (Cold forming) [1, 2].

Forming processes are defined that some of Manufacturing Processes to change the metal from a shape to another shape without changing in mass or chemical composition, so the metal surface which required to forming is in tangent with the tool, as well as the affection of the friction value produced between them [2].

Deformation in metal forming is defined as physical phenomenon occurred in metal through the forming process, to give some results in changing of the shape and the volume, which may be able to see and measure by some ways as a function to the strain in the metal which represents the positive and negative elongation when applying tensile or compressive load [3].

The strain may be divided to two parts [4, 5, 6]:

1. The elastic strain: is the strain in which the metal returns to its original shape after the removal of the load, and proportion with applied stress.
2. The plastic strain: is the strain which remains in the metal after the removal of the load, having the stability state, occur in the metal due to the applied stress over the elastic limit.

One of the forming processes, is the Rolling Process as manufacturing process applied in the industry to produce Plates, Strips, etc, so the produced materials which produced by the rolling process have good properties such as Surface Finishing, and the rolling as manufactured process is used in High Quality Productivity and Mass Production [5, 6].

So, the researchers interest in the field of engineering materials forming by the cold and hot rolling of the mechanical production. Some of them deal with the topic as technical side, another as designed side according to mathematical and logical calculations, the goal of all researchers is to reach to the best results in productivity in rolling process with less energy, high quality and maximum toughness.

Quanshe Sun, Faliang Jv, Weizhong Jiang [7] studied the effect rang of Annealing in various temperature on the mechanical properties of high toughness of titanium alloy under the effect of rolling process.

I. Schindler, M. Mistecky, M. Ruzicka, L. Cizek, [8] interested with the Effect of cold rolling and annealing on mechanical properties (tension, hardness and micro structure) of HSLA Steel alloy.

A. Kurc, M. Kciuk, M. Basiaga, [9] explained the Influence of cold rolling on the corrosion resistance of austenitic steel X5CrNi18-10 and the micro-hardness.

While the researcher Roberto Gerardo Bruna, [10] showed the Effects of hot and warm rolling on microstructure, texture and properties of low carbon steel.

The microstructure and other mechanical properties such as toughness, Yield Strength and Impact Strength for Ribbed Rods of medium carbon steel produced by rolling process were studied by Oyetunji A [11].

The researchers Akpan, Emmanuel Isaac and Haruna, Idoko

Andrew, [12] reviewed the Structural Evolution and Properties of Hot Rolled Steel Alloys as well as the tension and the hardness.

While Defa Li, et al, [13] presented a model of the effect of cooling process after rolling on microstructure and property of Nb -Ti micro-alloyed low-carbon bainite steel.

Through this quick overview of the range of researches and studies, mentioned above and other studies not mentioned in this paper, where all focused on forming process using the method of the cold and hot rolling to predict the mechanical properties such as the strength of tensile, compression, hardness and the transformation of the microstructure of the sets of alloy steels, Researchers have obtained the results that will improve and develop the plastic forming processes using a rolling operating.

With following the scientific research methodology in the field of plastic deformation and the use of the rolling process, current paper has focused on the study of the effect of the direction of rolling and the reduction ratio of metal thickness on some mechanical properties (such as tensile strength, hardness, average flow stress and microstructure) for medium carbon steel (DIN CK 45) using the process of cold rolling as one of the plastic deformation for ferrous metals operations, the fact that this type of metal is used in many applications, including devices and mechanisms of transfer of power and large hammers and parts of vehicles and other using, since the previous researchers did not address in this field to the direction of rolling factor, as the medium carbon steel (DIN CK 45) did not use it as a model in the research.

2. Theoretical Side

The cold forming process is one of manufacturing operations, in which the metals formed in room temperature, or nearby it, generally, it is possible to form the metals in cold working by using a temperature high than room temperature, since the separated boundary between the cold and the hot forming is represent by the recrystallization temperature that will be higher than room temperature for most materials,

The cold forming will characterize by a some features that qualify it to compete with the other of the formation processes: [2, 3]

1. The cold forming causes an increasing of the mechanical properties such as hardness and tensile strength, beside decreasing of other features like ductility.
2. The formed productions by using cold forming are characterized with fine surface finishing and external appearance.
3. Possible to precisely control on the dimensions and measuring of the productions that made by using the cold forming, so the cold forming will use as final stage to form the hot forming production.

Although that, the cold forming has determinants which may be in the consideration when using in the forming operations: [5]

1. The required high energy is the major disadvantages of cold forming, including requiring the use of equipment and devices made of metal materials, with high efficiency and resistance.
2. The amount of forming that can be done under a force or constant stress in the cold forming may be less than hot forming under the effect of the same stress, in addition to the ductility of the productions after cold forming operation.

The operations that request a tension of the metal through the die is often consider as cold forming operations, the types of cold forming such as rolling, drawing, extrusion, deep drawing and forging [3, 4, 5].

Rolling is a deformation process in which the thickness of the work is reduced by compressive forces exerted by two opposing rolls. The rolls rotate as illustrated in Figure (1) to pull and simultaneously squeeze the work between them. The basic process shown in our figure is flat rolling, used to reduce the thickness of a rectangular cross section. A closely related process is shape rolling, in which a square cross section is formed into a shape such as beam. [3]

Flat rolling involves the rolling of slabs, metal strips, rods, Pulleys, sheets, and plates—work parts of rectangular cross section in which the width is greater than the thickness. In flat rolling, the work is squeezed between two rolls so that its thickness is reduced by an amount called the draft, Fig (1) shows the cold flat rolling operation with the principle dimensions for the contact surface between the rolls and the metal.

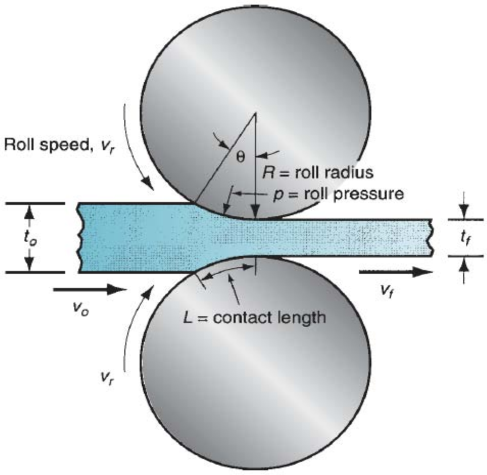

Figure 1: Flat cold rolling [5]

Flat rolling is illustrated in Figures (1) It involves the rolling of slabs, strips ,sheets, and plates—workparts of rectangular cross section in which the width is greater than the thickness. In flat rolling, the work is squeezed between two rolls so that its thickness is reduced by an amount called the (draft) in (mm units) [5]:

$$d = t_o - t_f \quad (1)$$

Where:

d = draft (mm), to = starting thickness, mm, and tf = final thickness, mm, Draft is sometimes expressed as a fraction of the starting stock thickness, called the (reduction).

$$r = \frac{d}{t_o} \quad \textbf{(2)}$$

In addition to thickness reduction, rolling usually increases work width. This is called (spreading), and it tends to be most pronounced with low width-to-thickness ratios and low coefficients of friction. Conservation of matter is preserved, so the volume of metal exiting the rolls equals the volume entering [5, 6]:

$$t_0 . w_o . L_o = t_f . w_f . L_f \quad \textbf{(3)}$$

Where (wo) and (wf) are the before and after work widths, (mm); and (Lo) and (Lf) are the before and after work lengths, (mm)

The true strain (ϵ) experienced by the work in rolling is based on before and after stock thicknesses. In equation form, [3, 4, 5, 6]

$$\epsilon = ln\left(\frac{t_o}{t_f}\right) \quad \textbf{(4)}$$

The true strain can be used to determine the average flow stress ($\bar{Y}_f$) applied to the work material in flat rolling. [4, 5]

$$\bar{Y} = \frac{K . \epsilon^n}{1 + n} \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

K: strength coefficient = (1200 MPa)
n :strain hardening exponent) = 0. 40(

The average flow stress is used to compute estimates of force and power in rolling.

The values of the factors (K) and (n) in equation (5) is according to the table (3. 4), pp: 47, of the reference (5), used for Steel, stainless, austenitic, annealed steel.

3. Experimental Procedure

3.1 Engineering Material

Medium Carbon Steel, defined by) DIN CK45) according to Germany Standard, (AISI 1045) according to American Society Standard [16], was used as engineering material in this paper, Modulus of Elasticity (200*103 N/mm2 ,) Tensile Strength Ultimate 585 MPa and the Tensile Strength Yield 450 MPa, table (1) shows the chemical analysis for medium carbon steel (DIN CK 45) which was used in the current paper and investigated in laboratories of the college of engineering.

Table 1: Chemical analysis for medium carbon steel (DIN CK 45)

Element	Mo	P	S	Si	Mn	C
Standard	-	0.035	0.03	0.4	0.5-0.8	0.42-0.5
Tested	0.027	0.005	0.005	0.277	0.61	0.458
Element	Fe	Ni	Cu	V	W	Cr
Standard	Rem	-	-	-	-	-
Tested	98.1	0.157	0.23	0	0.14	0.15

3.2 Planning

Table (2) represents the pre-planning of the current work to prepare a sufficient number of samples to cover the research objectives, taking into account the existence of three attempts for each value of the rolling direction and the percentage reduction in thickness. Figure 2 illustrates how the sample enters between the two rolls.

Table 2: numbers of required work pieces in the current paper

Rolling Direction	Draft Ratio of thickness				Sum
	15	20	25	30	
0 o	3	3	3	3	12
30 o	3	3	3	3	12
60 o	3	3	3	3	12
90 o	3	3	3	3	12
Sum of rolling work pieces					48
Tensile test work pieces before rolling					3
Hardness test work pieces before rolling					3
Microstructure test work pieces before rolling					3
Total tested work pieces					57

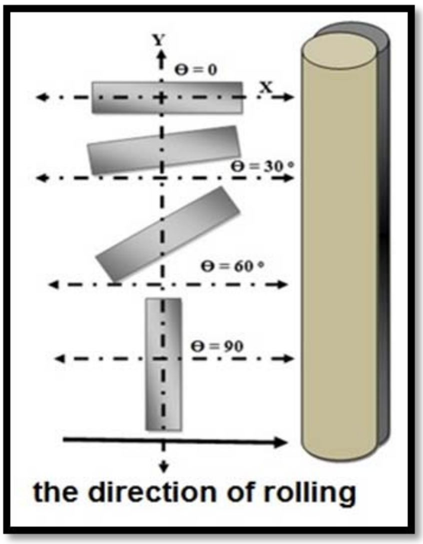

Figure 2: illustrates how the sample enter between the two rolls

3.3 Samples Preparing

The sample was selected with long 120 mm larger than the length of the contact line between the rolls and engineering material, [15], has been prepared in the form of a strip of medium carbon steel (DIN CK45), thickness (4 mm), by using a frequently chainsaw, have been carried out treatment rims and clean appendages sticking of shearing process using handle files, with a good cleaning of the surface of the sample surface from the oxidation using machine grinding up (25 microns) to ensure uniformity accuracy of dimensions for all samples. Has been initialized (57) tested samples according to the planning operation contained in the table (2), and encoded samples using effective chisels at the tip of each sample for the purpose of controlling the sort after testing. Fig. (3) shows the used dimensions of the sample in the current research.

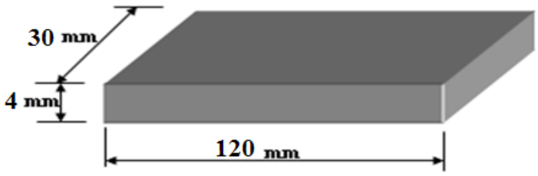

Figure 3: The used dimensions of the sample in the current research

3.4 Testing Procedure

Tension: (3) samples of medium carbon steels (Article of current search) were used according to applied measurements accredited laboratory for the purpose of testing them prior to the rolling process to determine the value of the stress and Strain using a device (Universal Testing Machine) Capacity (5 tons).

Hardness: by using Rockwell hardness tester SHR-150E to investigate the hardness of (3) samples of the engineering material.

Microstructure:
Three samples of engineering material used to know the microstructure before rolling operation, KELER reagent type of appearance solution was used to appear the samples, then wash the samples by water and alcohol and dried so that the sample will be ready to microstructure testing which was investigated by Olympus Bx 60M instrument with (10 X) number of zooming force, so, the pictures transferred to the computer to save by video digital camera.

Electric Rolling Machine with rolling capacity (2 mm ×1300 mm(was used to process the rolling operation, the roll diameter (83 mm), the distance between the two rolls (115 mm) with electrical motor (1. 5 KW), the lubrication was used for the rolls and controlling gears.

Four samples were inserted between the rolls in each stage of rolling, so the operation divided into four stages according to the draft showed in table (2).

In each stage, the first sample would inter at (0 o) that means the interring of the sample was perpendicular on the line between the two rolls, the second sample at (30 o), the third sample at (60 o), the forth sample at (90 o) that means the interring of the sample was parallel to the line between the two rolls, so the operation was repeated three times for each stage and use the average to ensure the accuracy of the results.

4. Results and Discussion

After the completion of the rolling process, tensile strength, hardness, and the microstructure examined of the samples which carried in rolling process with the use of the same as the previous tests devices, so has been the use of a package (office 2007) to treat the results and draw relations in the light of the theoretical and practical results of tests, it has been found values of each of tensile stress, average flow stress and hardness rate at each direction and the percentage reduction in thickness after using equations (4) and (5) and applied to practical results in getting strain rate and the practical average flow stress, taking into account the use of the actual sample thickness after rolling that not calculated mathematically (the default).

4.1 The relationship between the rolling direction and tensile stress

The existence of exponential proportionality Shown in Figure (5) between the angle of the direction of the cold rolling and the amount of tensile stress in both the theoretical or the practical side, and almost the results are process is very close to one another, with a clear increase from what it is in the theoretical side, and remains the effect of the vertical direction of rolling (90o) has a significant impact in increasing the tensile stress.

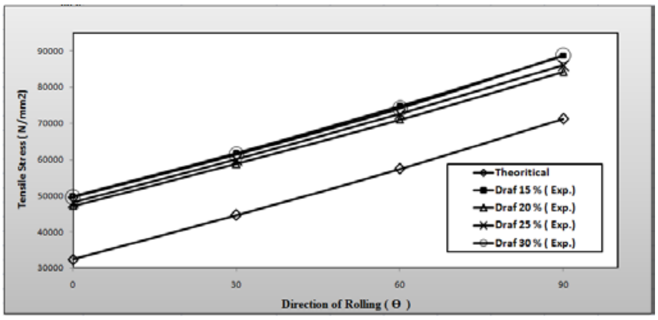

Figure 5: The relationship between the rolling direction and the average flow stress

4.2 The relationship between the rolling direction and average flow stress

Figure (6) shows the relationship between the angle of the direction of rolling and the average flow stress, calculated theoretically and practically according to the equation (5), as it depends on how much strain as a single variable in this equation, with the use of parameter values (K and n) contained in the theoretical side of the current research, notes from the figure, the average flow stress increases with increasing angle of the direction of the rolling process of the theoretical side at any point reduction in the thickness of the engineering material under the cold rolling process, practical results showed concave curve in every percentage reduction in the thickness of the engineering material at any angle of the direction of rolling, it means that the angle of the rolling direction will be an important factor in changing of the average flow stress during the cold formation process, and all angles located in the range (0< Ɵ < 90o) will take the shape of the concave curve where the average flow stress will be lower than it is in both horizontal and vertical directions for the arrange of entry of the samples, with the observation that the average flow stress in practice will increase with the increase in the percentage reduction in the thickness of engineering material.

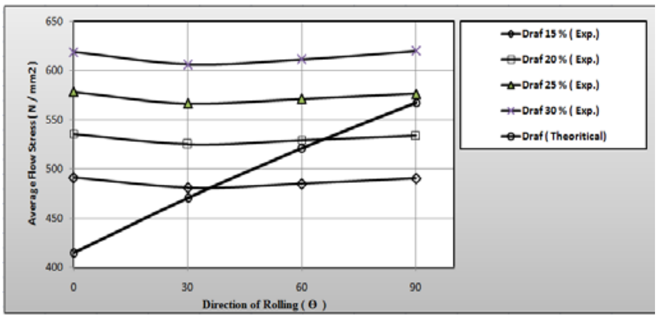

Figure 6: The relationship between the angle of the direction of rolling and the average flow stress

4.2 The relationship between the rolling direction and the hardness of the engineering materials

Figure (7) shows the relationship between the angle of the rolling direction and hardness of engineering material after its formation on cold forming using a rolling process, and notes from the figure, the amount of hardness of engineering material increases with increasing the angle of the direction of the rolling process at any point of reduction in the thickness of the engineering material under the cold rolling process, the practical results showed curve is convex in all proportion reduction in the thickness of the engineering material at any angle of the direction of rolling, and this means that the angle of the rolling direction will be an important factor in the change of hardness of engineering material during the cold formation process, and all angles located in the range (0< Ɵ < 90o) will take the form of convex curve, where the hardness of the engineering material will be more than it is in the horizontal and vertical directions in arranging the entry of samples, and at the same time, the practical value will increase with the increase in the percentage reduction of the thickness of the engineering material, and due to the process of strain hardening (Work hardening), which originates in the engineering material during the cold formation process.

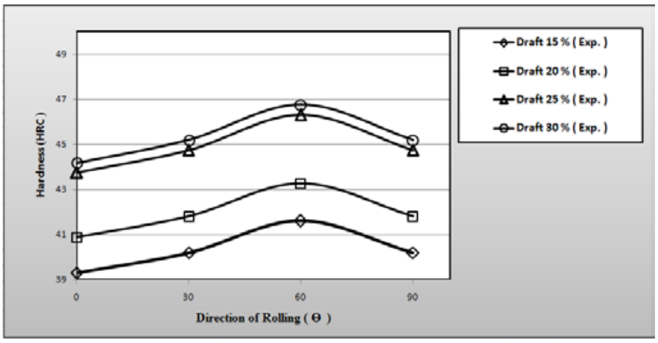

Figure 7: The relationship between the rolling direction and the hardness of the engineering material for varios of draft

It should be noted, that the value of the hardness of medium carbon steel used in the current research was up to (38 HRC) when tested before the formation process by Rockwell scale, but the experimental results showed that the value of the hardness of engineering material increases from basic value with the increase in the percentage reduction in the thickness of engineering material, which leads us to say that the cold formation process using surface rolling increases hardness property, especially when reducing the thickness of the engineering material by more than (20%) with increasing angle of the direction of rolling and will serve to improve the property of hardness, which was agreed upon some of the studies in this field [7, 8, 9, 10] and made by experimental readings.

4.3 The relationship between the rolling direction, the draft and the microstructure:

Figure (8) shows the microstructure of the engineering material prior to the cold rolling process, , that's clear from the figure that the concentration of martensite ratio (dark color) is greater than ferrite (light color), by using the method of counting the bullet to determine the martensite percentage and ferrite in specific surface area [2, 4, 8. 15], it was found that Martensite area accounts for about 67% within a specific area (1 cm2) while ferrite area limits (33%), that these percentages are able to give the engineering material hardness ranging from (45 HRC - 33 HRC).

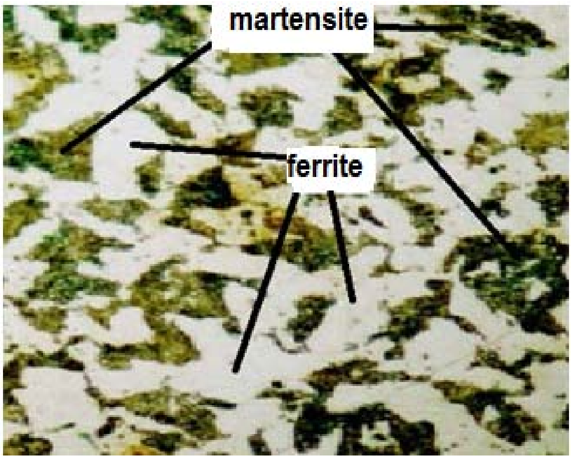

Figure 8: Microstructure of medium carbon steel (DIN CK45) before rolling operation

Figure (9) shows the microstructure of the engineering material after a cold rolling process, at the angle of the direction of rolling (0o) when the reduction ratio thickness of the engineering material (15% and 20% and 25% and 30%), shown in the figure that most of the components taken the horizontal direction, especially the two samples (A1 and A4) which shows the microstructure of the engineering material influenced by the direction of the formation process of the cold rolling.

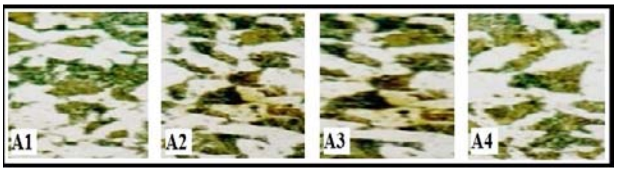

Figure 9: Microstructure of the medium carbon steel (DIN CK45) after rolling operation at angle (0 o)
A1: Draft 15 %, A2: Draft 20 %, A3: Draft 25 %, A4: Draft 30 %

Figure (10) shows the microstructure of the engineering material after a cold rolling process, when the angle of the rolling direction (30o) at the reduction ratio of the thickness of the engineering material (15%, 20%, 25% and 30%), and is shown in Figure that the microstructure of the Engineering material components inclined at an angle (30o).

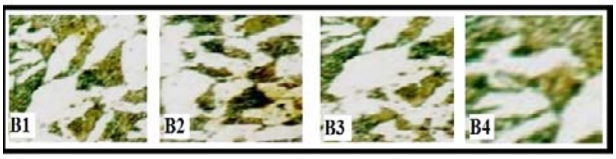

Figure 10: Microstructure of the medium carbon steel (DIN CK45) after rolling operation at angle (30 o)
B1: Draft 15 %, B2: Draft 20 %, B3: Draft 25 %, B4: Draft 30 %

Figure (11) shows the microstructure of the engineering material after a cold rolling process, when the angle of the direction of rolling (60o) at the reduction ratio 0f thickness of the engineering material (15%, 20%, 25% and 30%), and shows that the angle of the rolling direction (60o) that is clear influence in the microstructure.

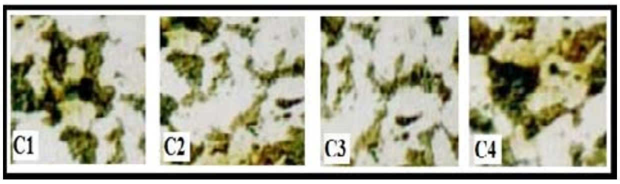

Figure 11: Microstructure of the medium carbon steel (DIN CK45) after rolling operation at angle (60 o)
C1: Draft 15 %, C2: Draft 20 %, C3: Draft 25 %, C4: Draft 30 %

Figure (12) shows the microstructure of the engineering material after a cold rolling process, when the angle of the rolling direction of (90o) at the reduction ratio of thickness of the engineering material (15%, 20%, 25% and 30%), samples components has appeared are moving toward vertical with very little change in varying proportions of the components of (0. 2%) compared with the sample before rolling when applying the manual counting method to calculate the components.

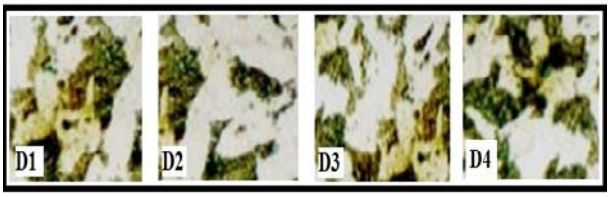

Figure 12: Microstructure of the medium carbon steel (DIN CK45) after rolling operation at angle (90 o)
D1: Draft 15 %, D2: Draft 20 %, D3: Draft 25 %, D4: Draft 30 %

5. Conclusions and Recommendations

5.1 Conclusions

In light of the results of the current study can be reached the following conclusions:

1. The rolling direction of angles located in the range (0< ϴ < 90o) has had a clear impact in increasing the tensile stress, especially when the direction of the vertical rolling, in addition to its effect on the average flow stress of the engineering material through change in the value of real strain during the plastic deformation.
2. The amount of draft in forming operation by rolling process is proportional to the increase in the average flow stress of the engineering material.
3. Engineering material hardness of cold rolling increases with every increase in the amount of reduction in the thickness of engineering material.
4. There is an increasing in the amount of hardness engineering material in the rolling process when the direction of entry of the sample inclined relative to the line between the rolls.
5. Microstructure of the material does not change in ratios of components, but the changing in the arranging and the shape of the components after rolling operation.

5.2 Recommendations

1. It is possible to use the current search results to predict the strength and energy required for cold forming.
2. Use the data of the current search to compare with other metals, ferrous metals and alloys.

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