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Design of Rolling Machine to Improve Mechanical Properties of Strapping-band Steel and Low Carbon Steel type SHP 440

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ABSTRACT

The modification of new roll machine should be able to produce very good mechanical and physical properties of different metal materials. Furthermore, this also can affect the microstructure of the metal. Conventional low carbon steel with a ferrite-perlite microstructure has relatively low mechanical properties. Due to it our research work refers to the mechanism of metal strengthening by means of grain refinement with the assumption that it will increase the strength and toughness of this Special High Performance (SHP) 440 low carbon steel. SHP 440 carbon steel with a maximum carbon content of 0.18% by weight C through a cold rolling process with size reduction variations of 10, 20, 30, 40, 50, 60 and 70%. The results showed that the most optimum increase in hardness values occurred in rolling with a size reduction of 70%, namely HB: 98 and increase of 16% from the initial hardness value, namely HB: 81.67 with a grain size of 8.20µm or decreased by 24.44% from the initial grain diameter of 10.85µm. In this research work it has been found that the greater the percent reduction in rolling size the hardness value of the SHP 440 low carbon steel will be higher.

Keywords: Rolling machine, low carbon steel, strapping band, SHP 440.

1. INTRODUCTION

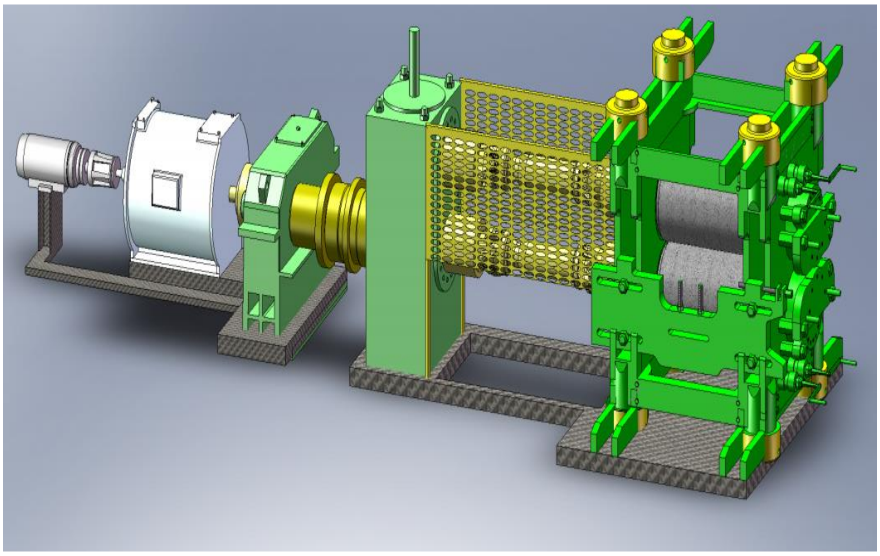
Design is a process that aims to improve and develop a system. The designer includes the shape, dimensions, and units, carried out to design product that can be used and useful in accordance with the desired purpose [1]. The design concept must clearly specify the desired performance of the designed product. Performance specifications are based on generally defined product performance which can be based on several key components of the product being designed. Detailed specifications can include configuration, shape, size and material specifications. Some explain several meanings engineering design [2].

The American Accreditation Board for Engineering and Technology (AABET) explains that engineering design is a useful activity directed at the goals of human needs, especially those achieved by using technology obtained in society. The definition states the important things that describe engineering design, namely having a specific function, aiming to meet human needs, based on technological factors. The general principles used in the design for modification of the gap system to be more efficient and accurate include the situation when rolling the gap position is in a fixed or unchanging condition where it is intended that the work-piece to be rolled or reduced does not experience defects during rolling. The design concept of this mini roll machine modification uses an automatic system that uses a hydraulic system to adjust the gap. Initially the design concept of this mini roll machine used a crank to adjust the gap, but now it will use a control to adjust the gap to be more efficient and accurate and automatic [3-5].

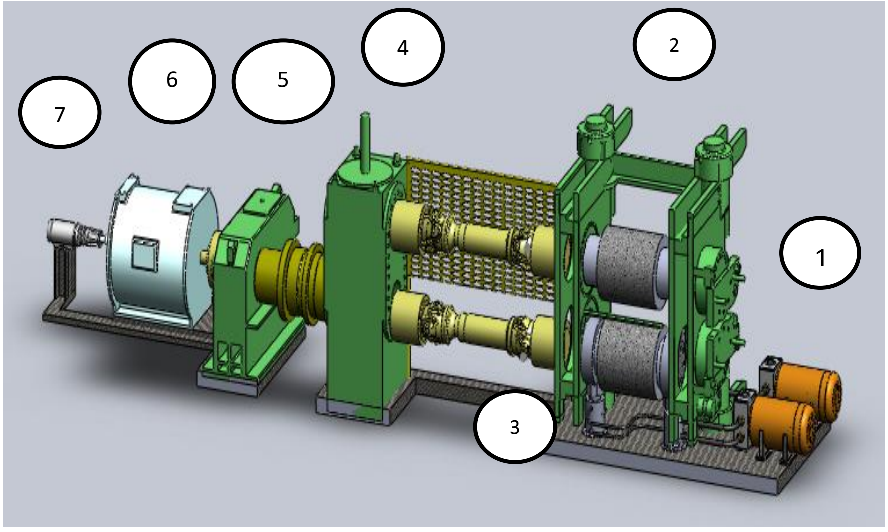
The use of low carbon steel dominates in the industrial world due to high economic value in comparison to other carbon steels. The mechanical properties possessed by low carbon steel are influenced by the grain size of the ferrite it has due to very low carbon content where the steel is soft and cannot be hardened but can be forged, cast, easily welded and can be hardened on surface by case hardening. The increase in strength becomes a barrier to plastic deformation conditions which is caused by changes in the metal structure that are hindered by the movement of dislocations. Dissolution of interstitial and substitutional atoms, strengthening and interaction and dislocation with grain boundaries or second phase particles will reduce the ability of dislocations to move by increasing the strength of the metal structure [6-7]. This research work considers the design of a modified roll machine design for several types of test samples where the first being the 0.18%C low carbon steel test sample and the industrial strapping band steel. Based on it, the design of the modified roller machine design will be applied to the rolling process of low carbon steel and strapping band type steel to improve mechanical properties.

2. METHODS

Gap modification is needed to adjust the shape and geometric size of the roller machine product used to obtain an accurate gap setting by increasing the productivity of the rolling process. Then planning a gap adjustment system that can move automatically, according to the desired size so that it can provide good product quality. Figure 1 depict the rolling machine design before and after modification.



(a)



(b)

Figure 1. Rolling machine design (a) Before modification (b) after modification

Table 1. Mini Roll Machine Components.

No	Component Name	Quantity	
(1)	Pump	2	Units
(2)	Roll	2	Couple
(3)	Hydraulics	2	Couple
(4)	Gearbox	1	Units
(5)	Reducer	1	Units
(6)	Drive Motor	1	Units
(7)	Tacho ampere	1	Units

Gap modification is needed to match the shape and size geometry of the roller machine product. More accurate gap adjustment to increase roller process productivity. An automatic movable and sized gap adjustment planning system is ensured which can provide better product quality. Figure 2 depict the soll workpiece geometry.

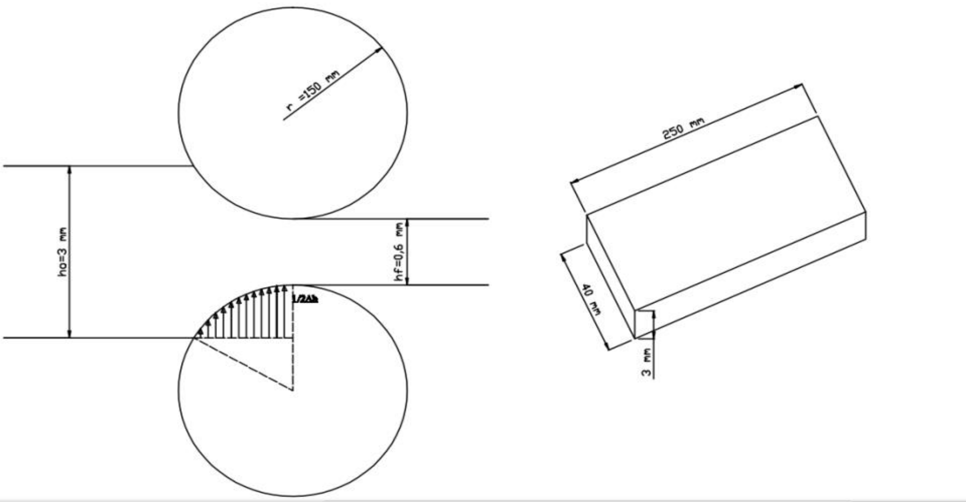


Figure 2. Roll workpiece geometry

Dimensions of the rolled product workpiece are as follows:

h_o = 3 mm

h_f = 0.6 mm

Roll Diameter = 300 mm

b = 40 mm

σ'_o = 335 N/mm^2

l = 250 mm

μ = 0.1

Loading: $P = \frac{2}{\sqrt{3}}\sigma'_o\left[\frac{1}{Q}\ (e^{Q}-1)b\sqrt{R\ \Delta h}\right]$ (1)

Amount of Reduction $\frac{\text{ho – hf}}{ho}\ x\ 100\% \frac{3-0.6}{3}\ x\ 100\%$ = 80%

Find the difference in thickness of the material in the roll (Δh)

$\Delta h = h_o - h_f$

= 3 mm – 0.6 mm

= 2.4 mm

Finding the Contact Surface Area between the Roller and the metal (Lp)

$$Lp = \sqrt{R\ \Delta h} = \sqrt{150\ x\ 2.4} = \sqrt{360} = 18.97 \text{ mm} \quad (2)$$

Finding the Average Thickness (h)

$$h = \frac{ho+hf}{2} h = \frac{3+0.6}{2}\frac{ho-hf}{ho} h = 1.8\ mm \quad (3)$$

Finding the Value of a Complex Function for Thick Reduction (Q)

$$Q = \frac{\mu\ x\ Lp}{h} Q = \frac{0.1\ x\ 18.97}{1.8} Q = 1.05 \quad (4)$$

$$P = \frac{2}{\sqrt{3}}\sigma'_o\left[\frac{1}{Q}\ (e^{Q}-1)\ x\ b\ \sqrt{R\ \Delta h}\right] \quad (5)$$

$$P = \frac{2}{\sqrt{3}}335\left[\frac{1}{1.05}(e^{1.05}-1)\ x\ 40\ \sqrt{150\ \ x\ 2.4}\right] \text{ P = 52425.09 } Kg$$

3. ANALYSIS AND RESULTS

3.1. Characterization of the results of the rolling process

The strapping band which is the reference as a comparison for all research test samples consists of two types, namely the strapping band from a steel company, with a green appearance which is an imported product as a coil binder resulting from hot rolling, and the other is the result of a laboratory scale which is a product for fastening coils resulting from cold rolling. The characteristics and chemical composition of grade steel can be seen in the Tables 2 until 4.

Table 2. Specifications of Test Samples for Low Carbon Steel

Standard Specification	**Tensile Properties**			**Tensile Test Form**	**Application**
	RE (N/mm^2)	RM (N/mm^2)	Elongation		
SHP440	310 – 390	440 - 540	1.4≤t≤2.0→29 min 2.0<t≤2.5→30 min 2.5≤t→32 min	Long	Automotive

Table 3. Chemical composition of HSM strapping band

JISG3101SS400		**%C**	**%Mn**	**%Si**	**%Al**	**%P**	
		0.16-0.18	0.8-1.0	0.15-0.3	0.025-0.5	≤ 0.025	
%S	%Cu	%Ni	%Cr	%Mo	%Nb	%V	%Ti
≤0.02	≤0.09	≤0.09	≤0.07	≤0.02	≤0.01	≤0.015	≤0.01

Table 4. Chemical composition of CRM strapping band

ASTM A611GrC		**%C**	**%Mn**	**%Si**	**%Al**	**%P**	
		0.12-0.14	0.5-0.7	0.1-0.15	0.026-0.5	≤ 0.02	
%S	%Cu	%Ni	%Cr	%Mo	%Nb	%V	%Ti
≤0.02	≤0.09	≤0.09	≤0.07	≤0.02	≤0.01	≤0.008	≤0.01

The quality of the steel strapping band depends on the chemical composition. It affects the mechanical properties such as strength, toughness and corrosion resistance. The function of the steel content needs to be known and to produce steel that suits with the needs of the industry. The chemical composition of the strapping band is as shown in Table 3 - 4. The mechanical properties of a metal are influenced by the grain size [8-12].

3.2. Mechanical Properties

The value of hardness and grain diameter obtained by metallographic observations on the initial test object can be seen in Figure 3. The microstructure of the initial test specimens included low carbon steel where the microstructure was dominated by the soft ferrite phase with high formability. The grain shape of the HSM strapping band is flatter, the grain size of the laboratory-scale strapping band is 11.2 μm and the HSM

Industrial is 7.9 µm. The hardness value of each strap is different, for lab scale strapping it is 65 HRB and industrial scale strapping is 86.6 HRB. The color is darker because the carbon element from the lab scale strapping band tends to be more. Tensile testing did not show any yield point and no change in length with a constant force where the proportional stress strain was seen to be longer in both lab scale and industrial scale strapping bands. For the lab scale the stress value is around 600 N/mm^2 at 1.25% strain, while the industrial scale is about 800 N/mm^2 with the same percent strain as. The maximum stress value for industrial scale strapping band is 928 N/mm^2, and for lab scale strapping band is 668 N/mm^2. These data indicate that the strapping band is a material that is processed by cold working. Effect of metal rolling reduction on the hardness of low carbon steel SHP440. From the rolling test with size reduction, hardness testing was carried out using the Brinell (HRB) method. The principle of this hardness test is that a steel ball with a certain diameter (D) is melted into the surface of the test object with a specific test force (F). the hardness value data is obtained in Table 5. From the data in Table 5 it is found that the relationship between the process variable and the hardness value is as follows:

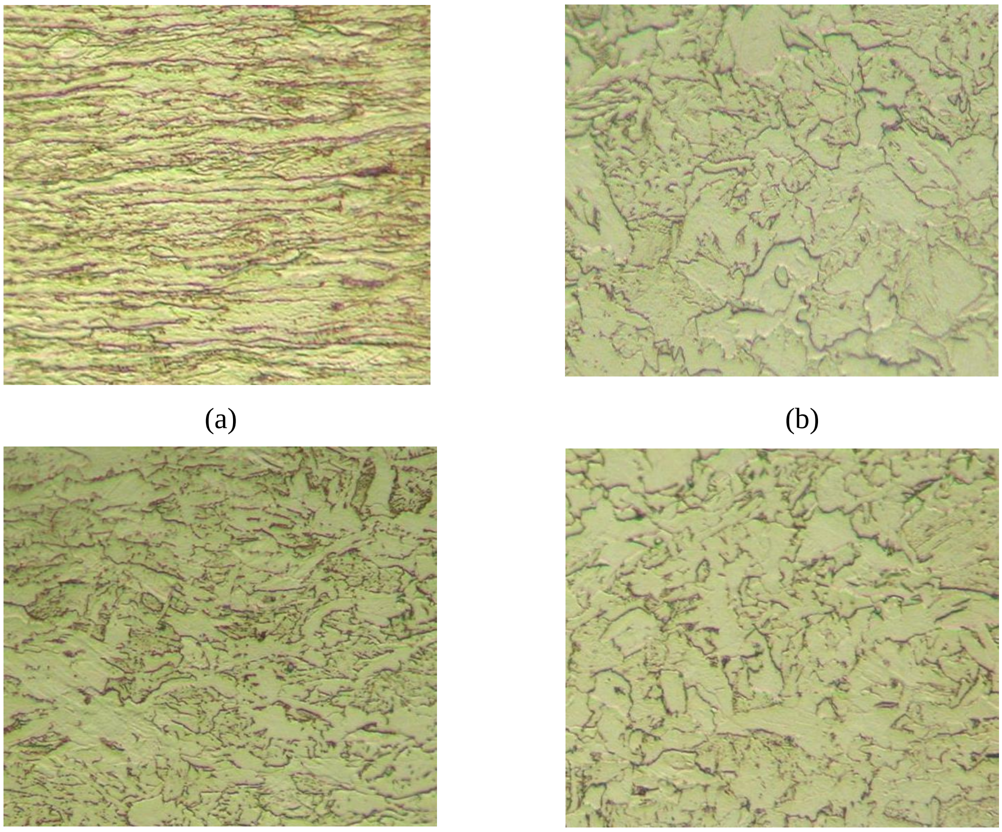
Table 5. Effect of Percent Reduction on Hardness Value (HRB)

R 0%	R 10%	R 20%	R 30%	R 40%	R 50%	R 60%	R 70%
82	90	93	94	95	96	97	98
81	88	93	95	95	96	98	98
82	90	92	94	95	95	97	98
81.67	89.33	92.67	94,67	95.00	95.67	97,67	98

3.3. Analysis of Microstructure on the object samples

The effect of reducing the size of rolling on the microstructure formed was observed through qualitative and quantitative metallographic testing using an optical microscope. Effect of percent reduction on microstructure of low carbon steel SHP440. Qualitative metallographic testing was carried out using an optical microscope. The CRM metallographic test was carried out to support the discussion of observations of the microstructure produced in this study. The photo images of the microstructure of cold rolling work in this study with variations in size reduction of 10 - 70% can be seen in Figures 3 to 4 below.

In Figure 3 and 4 are shown a microstructure of 0.18C low carbon steel which has a combination of iron (Fe) and carbon (C) and other alloying elements that are not too numerous to affect their properties [13]. The carbon content of this type of carbon steel is not more than 0.2% C. As well as a small number of other alloys such as manganese (Mn), silicon (Si), and copper (Cu) which have a maximum limit of no more than 2%. Low carbon steel has mechanical properties that are, it is soft and malleable. This is because, at very low carbon content, the microstructure of the material is dominated by the ferrite phase which has soft properties and has high formability.

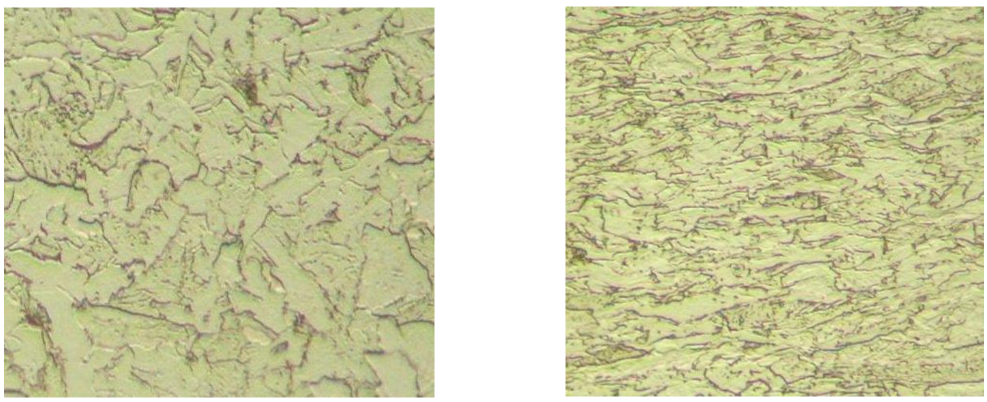


(a) (b)

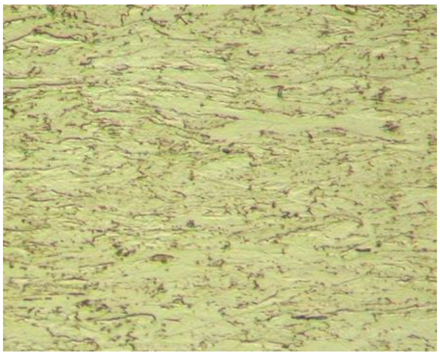
(c) (d)

Figure 3. Microstructure of *Low Carbon Steel*, 1000X magnification: a). Strapping Band HSM b). 0.18%C Reduction 10% c) 0.18%C 20% reduction d). 0.18%C 30% reduction.

The carbon content in SHP440 steel increases the hardness because the carbon content will form cementite (Fe_3C) deposits at the grain boundaries, or pearlite ($Fe+Fe_3C$) phase which has hard and brittle properties. The reduction of 10% and 20% of grain size was still uniform with grain size of 10.85 and 10.61, respectively, and the shape still tended to be round. The grain shape that tends to be round allows SHP 440 steel to have a relatively medium hardness value.



(a) (b)



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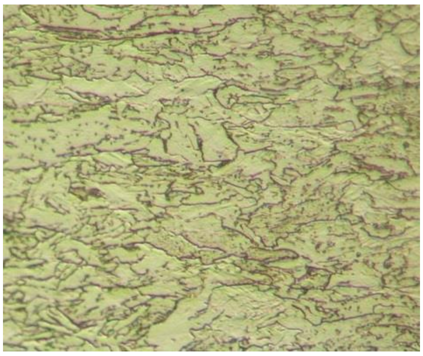

(d)

Figure 4. Microstructure of *Low Carbon Steel*, 1000X magnification: a). 0.18%C 40% reduction b). 0.18%C Reduction 50% C0. 0.18%C Reduction 60% d). 0.18%C Reduction 70%.

Figure 4 shows the microstructure resulting from cold rolling is ferrite (the bright part) and a little cementite which is concentrated at the grain boundaries. The microstructure of the test object with a size reduction of 10% - 30% which still has a shape that tends to be round even though it has been rolled, but the size reduction of 30% does not have a significant effect on changes in the shape of the resulting microstructure. The microstructure of size reduction 40-70% has a flat shape resulting from cold rolling. The grain size of the rolling samples with different size reduction variations has different grain size values. An example of calculating grain size on low carbon steel SHP440 using the Jeffries grain measurement method or Planimetry with the ASTM E 112 standard can be seen in Table 6.

Table 6. The Result of grain size on sample reduction of Roll process.

Reduction (%)	10	20	30	40	50	60	70
Grain Size (µm)	10,85	10,61	9,46	9,25	8,82	8,38	8.20

There was a decrease in size which was initially 10.85 µm when the 10% reduction decreased in size as the percent reduction increased until finally it was only 8.20 µm. This is due to recrystallization during deformation, the strain reaches a critical strain, sufficient energy to form nuclei at the grain boundaries. These formed nuclei will form fine grains in the material. The finer the grains in the material, the more grain boundaries there will be in the metal. Grain boundaries that act as barriers to the movement of dislocations will increase the strength of the metal. This mean that the greater the size reduction the deformation will result in the smaller grain size.

The results of the grain size reduction of up to 70% has been compared with the grain size of the strapping band both from the HSM which is 7.9 µm and from the CRM that correspond to 11.2 µm. The data that reaches a value with a size smaller or equal to the HSM strapping band, even for a reduction value of 70%, corresponds to the reduction value with the smallest grain size. Therefore, a larger reduction value is needed when a roller that is able to reduce the output is even thinner. The relationship between percent reduction to grain size is focused on the greater rolling reduction value and the higher mechanical properties of the test sample. Based on the Hell and Petch formula that the greater reduction should have finer grain size will be prove that the greater deformation given to material should correspond to the greater hardness value.

[14]. The fine-grained material is harder and stronger than the coarser grained material due to the fine grain that has a larger grain boundary area to prevent dislocation movement [15]. The quantitative relationship between yield strength y and grain size on grain boundary reinforcement has been formulated by Hell and Petch as equation (6).

$$\sigma_y = \sigma_o + k\, d^{-1/2} \quad (6)$$

Where σ_y is the internal stress between the crystal lattice in the opposite direction to the movement of dislocations in the grains, d is the diameter of the ferrite grains and k is a constant representing the degree of difficulty to open [16, 17]. Figure 5 depict the relationship of reduction to the grain size in roll-processed of Strapping-band Steel and Low Carbon Steel type SHP 440

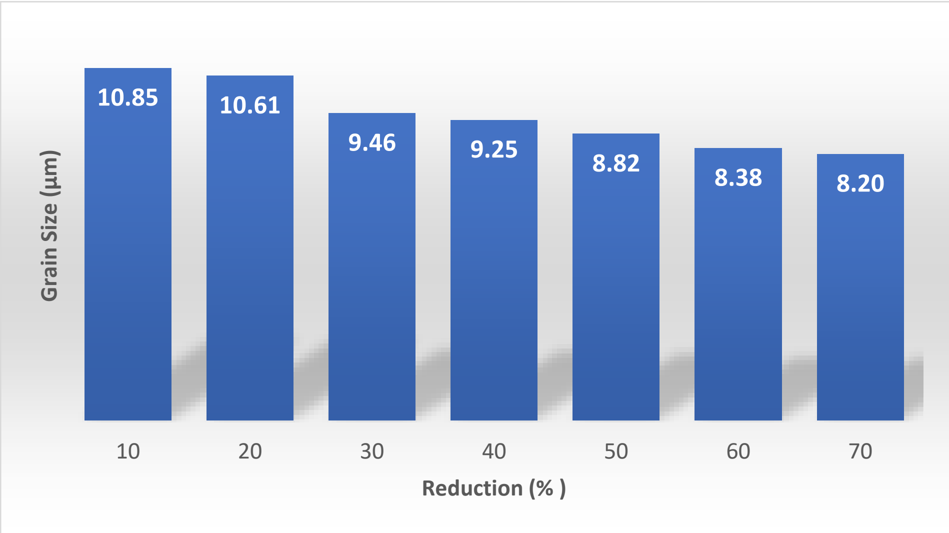

Figure 5. Relationship of reduction to grain size in roll-processed of Strapping-band Steel and Low Carbon Steel type SHP 440

4. CONCLUSION

In this paper we have briefly described the design of rolling machine to improve mechanical properties of strapping-band steel and low carbon steel type SHP 440. The results of mechanical properties and microstructure of SHP440 steel can replace the role of the CRM strapping band in its application. In case of HSM strapping band it has been seen that an adding a percent reduction was necessary to achieve optimum mechanical properties.

The results showed that the most optimum increase in hardness values occurred in rolling with a size reduction of 70%, namely HB: 98 and increase of 16% from the initial hardness value, namely HB: 81.67 with a grain size of 8.20µm or decreased by 24.442% from the initial grain diameter of 10.85µm. In this research work it has been found that the greater the percent reduction in rolling size the hardness value of the SHP 440 low carbon steel will be higher.

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CONFLICT OF INTERESTS

The authors would like to confirm that there is no conflict of interests associated with this publication and there is no financial fund for this work that can affect the research outcomes.

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