

A Comparative Analysis of Cold Rolling on Mechanical Properties of Aluminum

Cheruku Naveen Kumar ^[a], Dr. R. Nagendra Babu ^[b], T. N. Charyulu ^[c]

^[a] PG Student, Department of Mechanical, Sri Vahini Institute of Science and Technology, Tiruvuru, India.

^[b] Professor, Department of Mechanical, Sri Vahini Institute of Science and Technology, Tiruvuru, India.

^[c] Associate Professor, Department of Mechanical, Sri Vahini Institute of Science and Technology, Tiruvuru, India.

Abstract— In the Automotive industry today, structural body parts in Cars, Aeroplanes are generally made of rolled Aluminum(Al) alloy. An appropriate mechanical properties estimation tool for roll formed parts is not available in the market. Most existing roll forming tools concentrate on the process layout. To determine the mechanical properties of roll forming in a fast and accurate manner, a calculation system should be developed. This paper begins with a determination of mechanical properties by practical experimental investigations. The rapid calculation tool is then described. Finally, the paper is completed with an analysis and discussion of the experimental results.

In the present work, an Aluminum alloy is manufactured by using the solidification process. Al alloy is processed by cold rolling at 10,20,30,40 and 50% deformations in thickness using a two-high rolling mill at ambient temperature. This work examines the effect of rolling on mechanical properties like ductility, Ultimate Tensile Strength (UTS) and Hardness (BHN) behave with the increase in the percentage of rolling from 0 to 50 percent. A general behavior in roughness value and impact strength with the increase in the percentage of rolling is investigated. These results are examined by studying the microstructure and SEM micrograph results. This paper can be used as an estimation tool for any type of application to estimate the required mechanical property before rolling and the desired properties can be achieved by optimized rolling.

Keywords—Al alloy, Cold rolling, Strength, Ductility, Hardness, Roughness, Microstructure, SEM Micrographs.

I. INTRODUCTION

Aluminum is a remarkable material which possess a combination of qualities such as light weight, high strength, corrosion resistance etc., which makes it suitable for various engineering applications. Users of aluminum and of other metal strip products are seeking perfect flatness. Aluminum sheets used for cars, cans, etc. are obtained through cold rolling of aluminum. In the cold rolling process, aluminum of thickness approximately 4mm is reduced to 0.35mm. The yield strength of pure aluminum ranges from 7MPa to 11MPa while alloying with several alloying elements increases yield strength ranging from 200MPa to 600Mpa.

Rolling is a type of metal forming process in which material of certain thickness is passed through a pair or more number of rolls to get the desired thickness and properties. The schematic diagram of the rolling setup is presented in Fig. 1. Rolling is of two types basing on the temperature of the material rolled. If the temperature of the rolled material is higher than its recrystallization temperature, then it is called

as hot rolling and if the temperature of the rolled material is lower than its recrystallization temperature, then it is called as cold rolling. By performing cold rolling, the strength increases approximately by 20 percent due to strain hardening. It also results in a good finish and tighter tolerances. But cold rolling cannot reduce the thickness of the material as much as hot rolling.

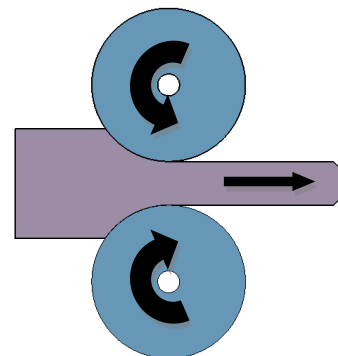


Fig. 1: Rolling Process

The present research investigates the effect of rolling on mechanical and microstructural properties of Al alloy. In recent years, Scanning Electron Microscopy (SEM) has become a useful technique for the fractographic study of engineering materials. The research work in this paper is involved with the collection of advanced experimental data and testing of engineering models in an experimental approach. Similarly, the computer models can be developed in any design software like CATIA V5 and can be validated through numerical simulation like ANSYS. The obtained simulation results can be compared with the experimental results. This research is of great advantage to the automotive and aerospace industries.

II. EXPERIMENTAL PROGRAM

A. Preparation of Al Billets

Rectangular test samples available in the market as an Al alloy cast ingot melted in an oil-fired furnace are used for this work. The chemical composition of this samples is presented in Table 2.

The preparation of billets mainly consists of five major steps:

1. A collection of Al alloy cast ingots.
2. Melting of Al alloy samples in Oil fired furnace.
3. The setting of Dies in Position.
4. Pouring Red Hot molten metal into the Cast Iron Dies.
5. Solidification of the Molten Metal in the die.

B. Rolling of Billets

The billets were then rolled at ambient temperature 25°C, using a two-high mill aligned with thickness reduction varying from 0 to 50 percent. The thicknesses of the rolled billets are presented in Table 1.

Main parts of the Rolling equipment are:

- Electric Motor
- Fly Wheel
- Gear Train set up
- Clutch
- Lifting arrangement of rollers
- Rollers

Rolling Machine Specifications:

- Motor Speed - 1140 rpm
- Roller Speed - 36 rpm
- Roller Length - 32 inches
- Roller Diameter - 13.5 inch
- Cast billet thickness - ¾ inch
- Minimum possible thickness - 23 gauges

In this work, the billets are rolled or deformed to five different percentages of Rolling.

Table-1: Indicates the initial and final thicknesses of the billets:

S. No	% of Rolling	Initial Thickness (mm)	Final Thickness (mm)
1	Cast Billet	16.06	16.06
2	10%	16.06	14.45
3	20%	16.06	13.38
4	30%	16.06	11.24
5	40%	16.06	9.63
6	50%	16.06	8.03

C. Preparation of Specimens for Mechanical Testing

Test specimens are prepared to required dimensions by cutting with hack-saw and machining on Lathe. The tensile specimens are machined according to ASTM standards. The dimensions of the tensile specimens are presented in the Fig.2. Izod impact test specimen normally measures 75x10x10mm and have a notch machined across one of the larger faces. The V-notch impact specimens are prepared with 2 mm depth as shown in Fig.3. The metallographic specimens are prepared by mounting, grinding and polishing by use of alumina Nano powder. Similarly, the required specimens are prepared as per the test standards for various tests like hardness, composition investigation, surface roughness, SEM photographs.

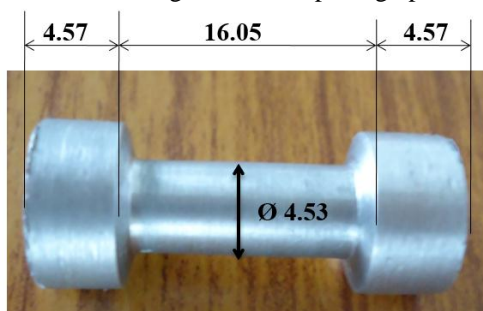


Fig. 2: Cylindrical tension test specimen

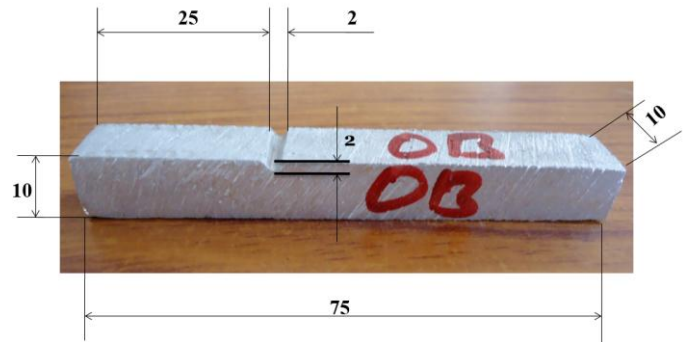


Fig. 3: Impact specimen (dimensions in mm)

III. EXPERIMENTAL INVESTIGATIONS

This section provides details of the experiments conducted and the equipment used.

A. Chemical Analysis

Non-ferrous spectrometer is used to know the composition of Al cast billet in the present work. The chemical composition is presented in the Table 2.

B. Roughness Test

Mitutoyo SJ-201 surface roughness tester of measuring range 17.5mm and detector range 360µ is used to investigate the surface roughness of the cast and rolled billets. The results are given in Table 3.

C. Impact Test

Izod impact test is carried out to investigate the impact energy of the test specimens. The specimen is clamped into the apparatus vertically and the other end is free like a cantilever beam configuration with the notch facing toward the pendulum. The tests are performed and the results of the impacts tests are averaged in the units of J/mm² and illustrated in Table 4.

D. Tensile Test

The electronic Tensometer of capacity 20kN is used in the present work to evaluate the tensile strength and ductility of the Al alloy test specimen. The line graph is displayed on the computer monitor which is connected to the equipment. The instrument is offered with DC servo motor drive and digital indicating unit. The specimens are operated at a constant crosshead speed of 1mm/min and the results presented in Table 5.

E. Brinell Hardness Test

Brinell hardness testing machine with a hydraulic power pack and control circuits having loads of 500 to 3000kgf in stages of 250 is used to examine the Hardness number (HRN) of Al alloy. The test uses a carbide indenter pressed into the sample by an accurately controlled test force for a specific dwell time of 15 sec. The test setup and the formula to calculate the BHN is shown in Fig.4. The size of indent is determined optically by measuring two diagonals of the round indent using a portable microscope. The average of the two diagonals is used in the following formula to calculate the Brinell hardness. The results are shown in Table 6.

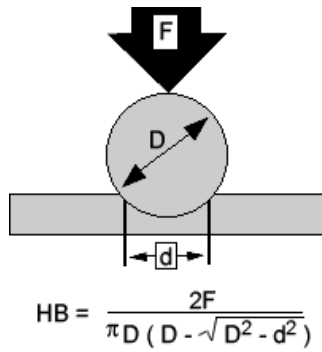


Fig.4: Indentation and load application on the specimen in the Brinell's test

F. Microstructure Analysis

VFM 9100 Metzer Metavision advanced binocular metallurgical microscope linked with a computerized imaging system is employed for determining the microstructure of the specimens. Photomicrographs of samples are taken at X400 magnifications as shown in Figures 5 to 10.

G. SEM Phtographs

Scanning Electron Microscope (SEM) with an Energy Dispersive Spectrometer (EDS) with a magnification of X330, resolution of 50µm, accelerating voltage of 20kV and imaging modes of Secondary Electron Image (SEI) is used for surface topography observation and element analysis of the samples and the observations are shown in Figures 11 to 16.

IV. EXPERIMENTAL RESULTS

A. Chemical Analysis of the Specimen

The chemical composition of the material as obtained by the spectroscopic analysis is given in Table2. The major alloying elements/impurities in Al are Fe, Si, Mg, Mn and Zn.

Table-2: Chemical composition (wt.%) of the material used:

Si	Fe	Cu	Mn	Mg	Zn	Ni	Cr	Pb	Sn	Ti	Al
0.38	1.06	0.23	0.13	0.25	0.25	0.03	0.02	0.17	0.01	0.01	Bal

B. Roughness Results

Table-3: Experimental results from Roughness Test

S. No	Specimen	Roughness (µm)
1	Cast billet	1.57
2	10% Rolled	0.68
3	20% Rolled	0.49
4	30% Rolled	0.39
5	40% Rolled	0.26
6	50% Rolled	0.14

C. Results of Izod Impact Test

Table-4: Experimental results from Izod Impact Test

S. No	Specimen	Impact Strength (J/mm²)
1	Unrolled	0.3047
2	10% Rolled	0.2139
3	20% Rolled	0.2649
4	30% Rolled	0.1566
5	40% Rolled	0.2811
6	50% Rolled	0.1486

D. Results of Tensile Test

Table-5: Experimental results from Tensile Test:

S. No	Specimen	Sample	Engg UTS (N/mm²)	Avg (N/mm²)	True UTS (N/mm²)	Avg (N/mm²)	Break Disp.	Avg (mm)
1	Unrolled	Sa1	115.1	107.35	128.6	122.75	3.58	4.73
		Sa2	99.6		116.9		5.88	
2	10% Rolled	Sa1	127	127.6	141.1	141.75	3.63	3.575
		Sa2	128.2		142.4		3.52	
3	20% Rolled	Sa1	144.3	136.1	149.3	145.95	2.18	2.28
		Sa2	127.9		132.6		2.38	
4	30% Rolled	Sa1	180.0	183.65	189.9	192.85	1.5	1.59
		Sa2	187.3		195.8		1.68	
5	40% Rolled	Sa1	203.1	206.75	210.0	213.2	1.05	0.98
		Sa2	210.4		216.4		0.91	
6	50% Rolled	Sa1	205.6	209.25	214.0	222.1	0.69	0.69
		Sa2	212.9		230.2		2.12	

E. Brinell Hardness Results

Table-6: Experimental results from Brinell Hardness Test

❖ Indenter Diameter used 5 mm

S. No	Specimen	Indentation Diameter (mm)	Brinell Hardness Number (BHN)
1	Unrolled	2.49	47.93
2	10% Rolled	2.37	53.28
3	20% Rolled	2.11	68.16
4	30% Rolled	2.09	69.53
5	40% Rolled	2.01	75.46
6	50% Rolled	1.94	81.26

F. Microstructures

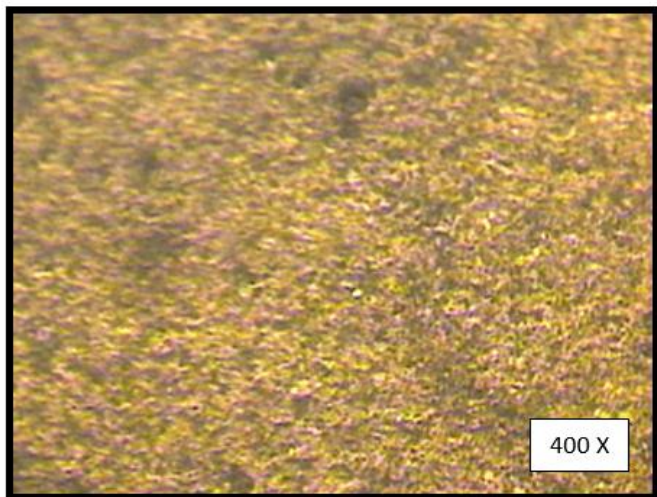


Fig. 5: Microstructure of Cast Al Billet



Fig. 8: Microstructure of 30% Rolled Al Billet

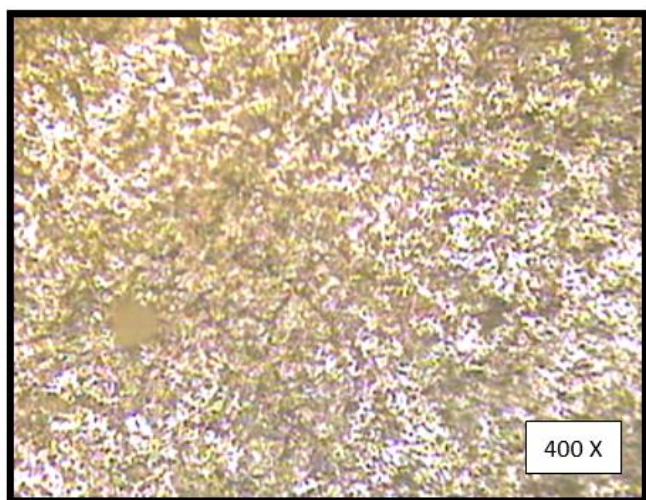


Fig. 6: Microstructure of 10% Rolled Al Billet

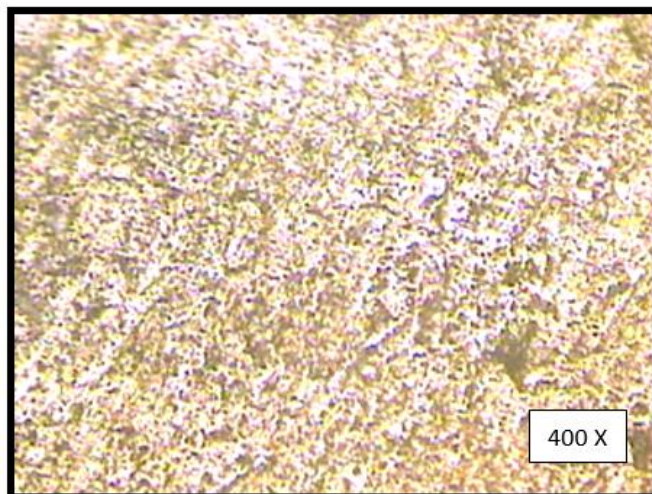


Fig. 9: Microstructure of 40% Rolled Al Billet

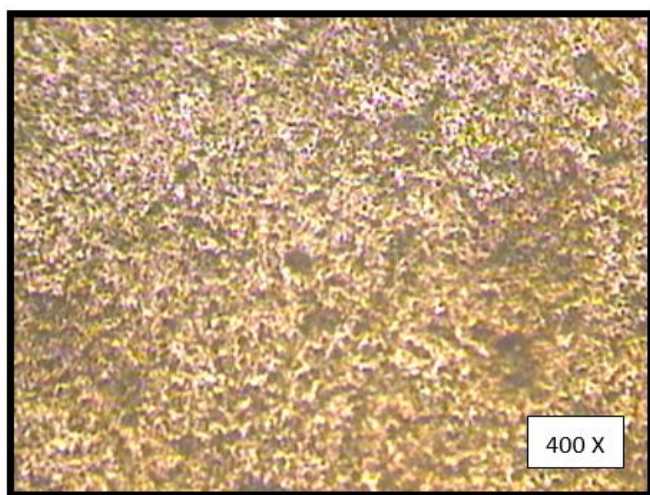


Fig. 7: Microstructure of 20% Rolled Al Billet

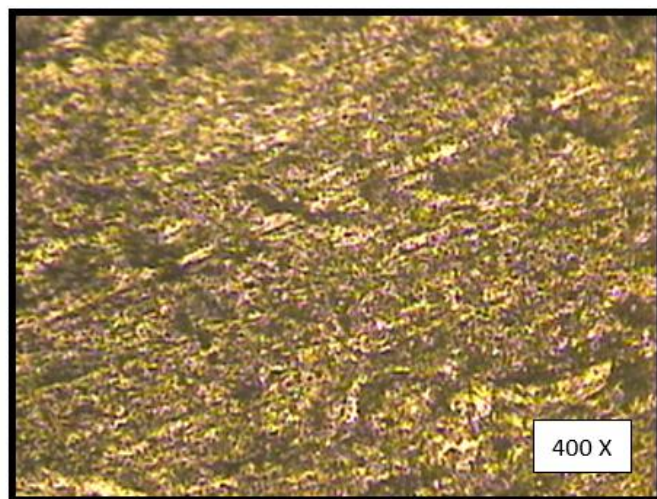


Fig. 10: Microstructure of 50% Rolled Al Billet

G. SEM Photographs

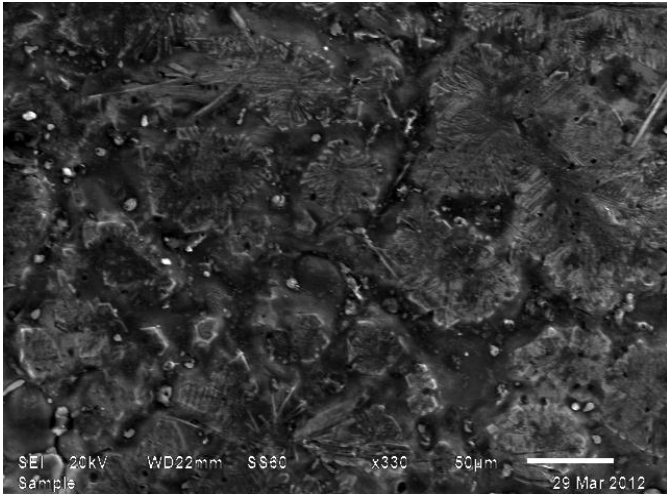


Fig. 11: SEM photograph of Cast Al Billet

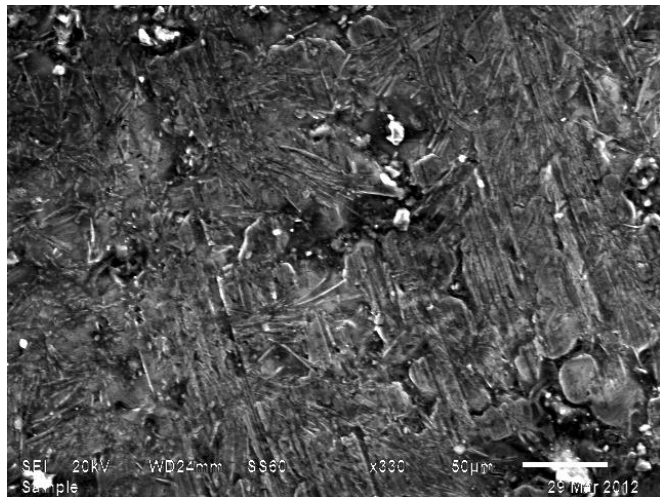


Fig. 12: SEM photograph of 10% Rolled Al Specimen

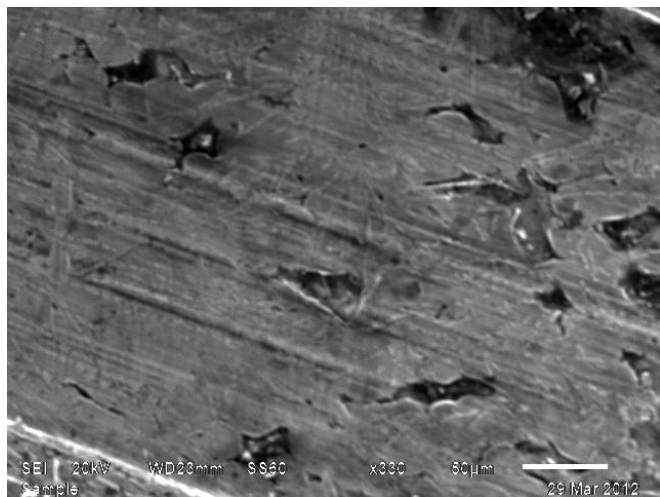


Fig. 13: SEM photograph of 20% Rolled Al Specimen

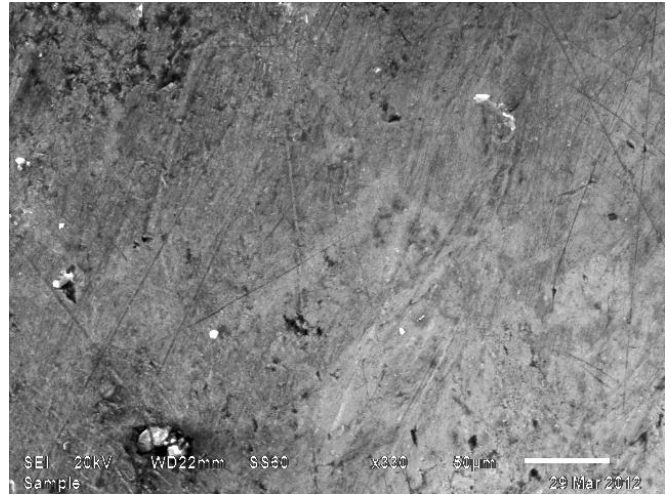


Fig. 14: SEM photograph of 30% Rolled Al Specimen

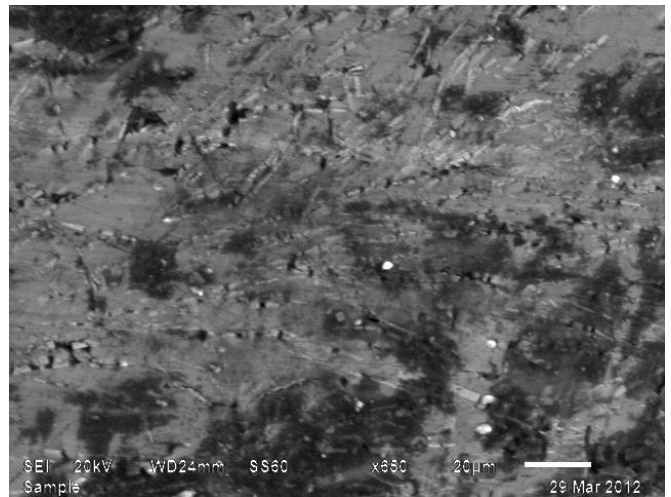


Fig. 15: SEM photograph of 40% Rolled Al Specimen

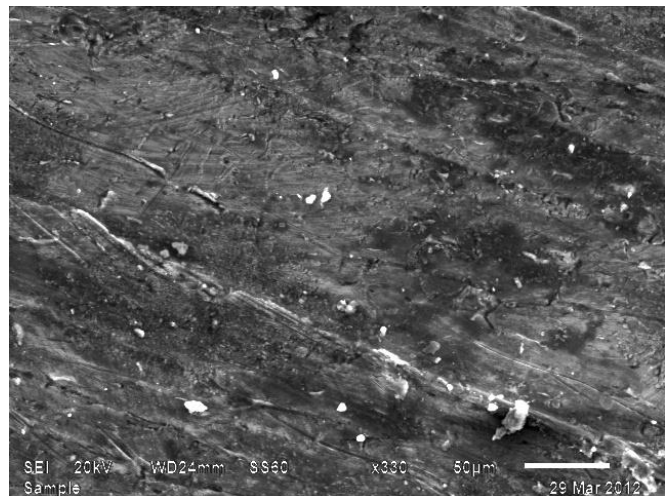
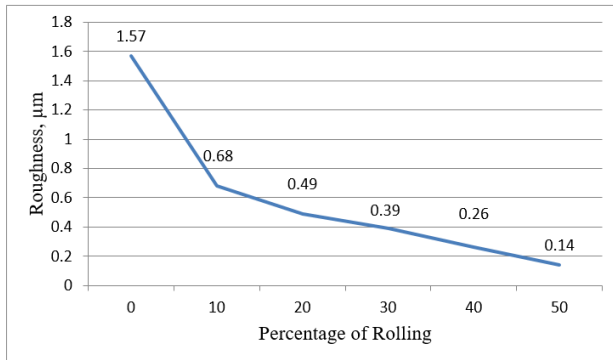


Fig. 16: SEM photograph of 50% Rolled Al specimen

V. DISCUSSION OF RESULTS

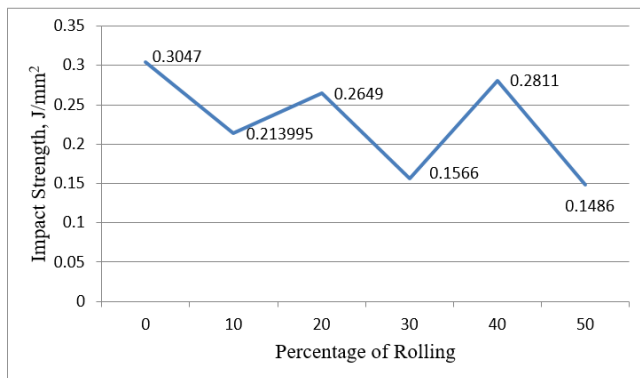
A. Roughness



Graph. 1: Effect of Rolling on Roughness

The effect of rolling on the surface roughness is as shown in the graph-1. A general decrease in roughness value with the increase in the percentage of rolling is observed. With increase in the percentage of rolling, the rolling load's increases which decreases the microscopic irregularities on the surface. With the load applied, the deformation of the irregularities occurs leading to the better surface finish.

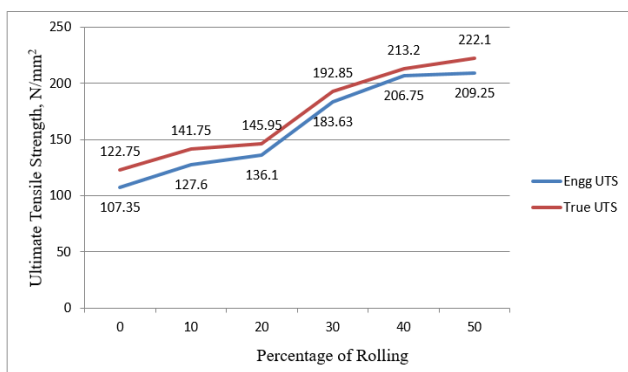
B. Impact Strength



Graph. 2: Effect of Rolling on Impact Strength

The effect of rolling on the Impact Strength is as shown in the graph-2. No general trend is observed in the results obtained. In the present experimental investigation, the impact energy varied from 0.3047 to 0.1486J/mm².

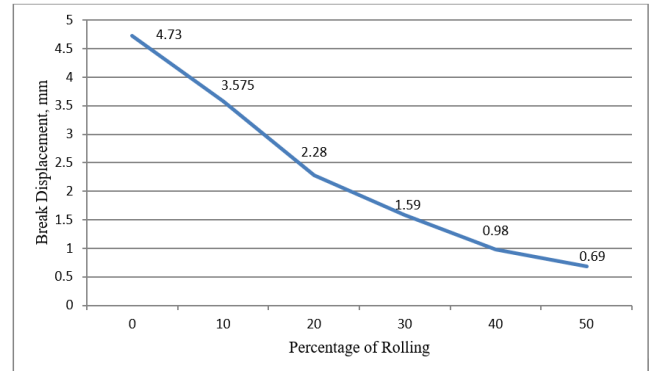
C. Ultimate Tensile Strength



Graph. 3: Effect of Rolling on UTS

The effect of rolling on the ultimate tensile strength is as shown in the graph-3. With increase in the percentage of rolling the strength increased. This can be attributed to increasing in strain hardening with increase in the percentage of rolling.

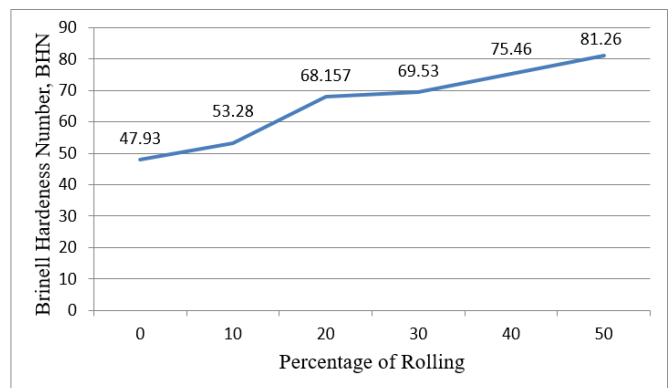
With increase in the percentage of rolling, the plastic deformation increases which results in the increase in several dislocations. As the number of dislocations increases, the resistance offered to the flow increased resulting in increase in the strength of the material.



Graph. 4: Effect of Rolling on Break Displacement

Graph-4 shows the effect of rolling on the break displacement. With the increase in rolling, the break displacement decreased and this is due to the increase in strength of the material. The break displacement varies from 4.73mm to 0.69mm.

D. Hardness



Graph. 5: Effect of Rolling on Brinell hardness

The hardness of test samples increased linearly within 0-20 percent thickness reductions, whereas there is no significant increase in hardness between 20 and 30 percent thickness reduction. At 30 percent and beyond, hardness values increase gradually to the maximum, 81.26BHN, at 50 percent reduction. The reason for this is that at 20-30 percent reduction, there seems to be temporary saturation in the generation of immobile dislocations. The fragmentation of grain boundaries because of the size reduction enhances the dislocation generation. The specimen elongation increases as the BHN values increases.

Variation of hardness with the extent of rolling is shown in the graph-5. The hardness increased gradually with the extent of reduction of thickness. The gradual increase in hardness with an increase in the extent of rolling may be attributed to the progressively finer dispersion of the fragmented particles.

E. Microstructure

The microstructures of the cast and rolled billets were shown in Figures 5 to 10. As the percentage of rolling increases, the grains get fragmented and increase in length. This is particularly observed for the microstructure of 30% rolled sample.

F. SEM Micrographs

Microstructure contains primary aluminum dendrites, eutectic silicon crystals, iron-based intermetallic and copper based intermetallic. The analysis of thin foils has validated the fact, that the structure of the investigating alloys consists of the solid solution α -Al (matrix) and an intermetallic secondary phase β -Si.

The volume of Mg_2Si precipitates in the aluminum matrix increases with the amount of the size reduction performed on the test specimen during cold rolling. The solute texture changes from a coarse precipitate to a fine one. Grain boundaries were broken up as the size reduction increased. This is clearly revealed from the SEM photographs shown in Figures 11 to 16.

VI. CONCLUSION

The work conducted revealed that cold working of aluminum alloy impacts significant effects on its mechanical properties. From this work, the changes occurring in the mechanical properties of the alloy were determined by changing the percentage of rolling. This work has shown that size reduction through cold rolling at room temperature could be used to increase dislocation motion while still improving the UTS and BHN characteristics of the material. It has been shown that hardness and strength increased from 0 to 50 percent thickness reduction. A substantial decrease in roughness and ductility is observed. Finally, the results obtained in this paper determines the estimation tool to get a required mechanical property before rolling for any type of application. Coming to the future work, the influence of rolling on mechanical properties of Al alloy is to be validated through numerical simulation of standardized tests using CATIA and ANSYS. The simulated results are to be compared to obtained experimental results for better accuracy.

REFERENCES

- [1] S.O.Adeosun, S.A.Balogun, Effect of Heat Treatment on strength & ductility of Rolled & forged Al 6063 Alloy, Journal of minerals & Characterization & Engg, Vol. 9, No.8,pp.763-773,2010.
- [2] Sanmbo A. Balogun, Effects of deformation Processing on mechanical properties of Al Alloy 6063, The Minerals, Metals & Materials Society and ASM International 2007.
- [3] S.K.Shaha, A.S.W.Kurny,Effect of Rolling on microstructure & wear properties, International Journal of Innovative Materials and Processing Technology.
- [4] Mohammad Tajally, Zainul Huda, A comparative analysis of tensile and impact-toughness behaviour of cold-worked and annealed 7075 aluminum alloy, International Journal of Impact Engineering 37(2010).
- [5] A thesis submitted to the graduate school of natural and applied sciences of Atılım University-by Mehmet Halil Akcan.
- [6] TALAT Lecture 1301, The Rolling of Aluminum: The process and the Product, prepared by Roy woodward, Aluminum Federation, Birmingham.
- [7] TALAT Lecture 3210, Continuous casting of Aluminum, prepared by Dr.Ing. Catrin Kammer, Goslar
- [8] S.X. Zhou, Jue Zhong, Experimental study on material properties of hot rolled and continuously cast aluminum strips in cold rolling