International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 14, Number 12 (2021), pp. 1197-1201

Manufacture of a rolling machine and an investigation of the effect of rolling speed on thickness reduction and microhardness during the accumulative roll-bonding (ARB) process

M. Pita[1*], P.M. Mashinini[2], L.K. Tartibu[2]

[1]*Department of Mechanical Engineering, Faculty of Engineering and Technology, University of South Africa.*

[2]*Department of Mechanical and Industrial Engineering Technology, Faculty of Engineering and Built Environment, University of Johannesburg.*

Abstract

A sheet metal rolling machine reduces the thickness of flat plates and convert a flat sheet into a hollow cylinder. A new approach for producing ultrafine grain materials with improved mechanical properties is severe plastic deformation. This paper presents the manufacture and accumulative roll-bonding process test of an affordable three-speed, two-roller rolling machine. The machine consists of a steel frame, an alternating current motor, a reduction gearbox, two mild steel rollers, pulleys, a V-belt, couplings, a hydraulic jack and a dial gauge. The machine was designed and manufactured and used to perform an accumulative roll-bonding process test on a strip of aluminium (Al 1050-H4) alloy at three different speeds (9, 18 and 36) with a constant pressure of 3 ton. A microhardness test was also performed on a parent and rolled samples using the ASTM E384 test method. The results show that material thickness was reduced by 29% at all three speeds. The parent sample was the softest with an average of 40.3 HV, while the sample rolled at 36 rpm was the hardest and was reported to be 49 HV.

Keywords: speed, thickness, material, rolling, machine, hardness.

1. INTRODUCTION

Nanofabrication refers to the processes and methods used to create engineered nanostructures and devices with dimensions of less than 100 nanometres [1]. Nanomaterials, also known as nanoparticles, are used in a wide range of applications [2]. Nanoparticles are the most common nanoproducts developed on a large scale, but they can also be used as by-products in the production of other materials [2]. The synthesis of nanomaterials and the fabrication of nanostructures can be divided into two categories: bottom-up and top-down approaches [3].

Bottom-up nanofabrication refers to the self-assembly of atoms or molecules in order to create multifunctional nanostructured materials and devices [1]. In the top-down method, a large uniform piece of material is reduced in size in order to produce the necessary nanostructures [4]. Using extreme plastic deformation (SPD) techniques, the microstructure of coarse-grained metals and alloys can be optimized to sub-micrometre and even nanometre scales [5]. High-pressure torsion (HPT), equal-channel angular pressing (ECAP), accumulative roll-bonding (ARB), multiple forging (MF), twist extrusion (TE), milling operation, and other are SPD methods.

Rolling the sheets to reduce the thickness to 50% is the accumulative roll-bonding (ARB) technique. The rolled materials are then cut into two pieces and stacked together, a process that can be repeated many times [6]. The ARB approach employs traditional rolling facilities that have two horizontal shafts that are free to rotate due to mechanical automation. The samples are pushed through the rollers in the first pass during the manufacturing process. The sample is gripped by the two horizontal shafts, which drive it through the rollers. The deformed material is cut into two sections, then stacked and rolled once more. This procedure can be repeated as needed.

As a result of globalization, it is critical that manufacturers produce products that are as reliable as possible [7]. Metal forming is a process that involves plastic deformation of a material to achieve the desired size and shape without causing significant material loss [8]. Sheet metal fabrication plays an important role in the metal manufacturing world [9]. Sheet metal is used in the production of materials ranging from tools, to hinges, to automobiles, to name just a few [10]. A two-roller sheet metal rolling machine uses a process of converting metal sheets of varying thicknesses into hollow cylinders or reducing the thickness of the plates being rolled [11].

Plate or sheet-bending rolls are divided into two categories: single pinch and double pinch, but their geometry and style may differ. Three-roll initial pinch, three-roll double pinch, four-roll double pinch, three-roll variable translating, three-roll pyramid, and two-roll systems are all popular machine types. For specific applications, plate rolls can also be designed in a vertical format. It's critical to choose the most suitable machine style for the job. Two-roll machines are made for thin materials that need to be rolled to a certain thickness. Aluminium is a soft and light metal that is primarily used in the automotive and aerospace industries.

Hardness is not a property inherent in any material; rather, it is a trait derived from the material's composition, thermal and mechanical background, and, most importantly, the structure of the specimen in question [12]. Indentation hardness testing is a simple way to look at the mechanical properties of a small amount of materials [13]. The Vickers hardness test involves indenting the test material with a diamond indenter in the shape of a pyramid with a square base and an angle of 136° between opposite faces under a test force ranging from 1 gf to 100 kgf. Normally, the entire load is applied for 10 to 15 seconds [14]. The hardness test of a metal material measures only the material's surface resistance to plastic deformation. The hardness test is widely used because it is a low-cost, non-destructive, and straightforward method of evaluating different material properties [15]. Microhardness testing is easy, convenient, and only requires a small area of the specimen surface for testing. The specimen surface is impressed with a Vickers diamond indenter at a specific load for a specific period of time using this technique [16]. Grain size decreases as this material is rolled multiple times via a two-roller rolling system, and mechanical properties and surface temperature rise. However, as the surface temperature rises as a result of continuous rolling, grain growth occurs, weakening the mechanical properties.

The authors needed a small, inexpensive two-roller rolling machine to perform the ARB experiment. Most of the machines available on the market were too expensive, therefore, the authors saw a need to design and fabricate a small, inexpensive and user-friendly machine for this experiment. To satisfy the study objectives there were certain requirements for designing a two-roller rolling machine in order to perform the ARB experiment; it had to be portable, reliable and affordable.

2. METHODOLOGY

2.1 Rolling machine design and fabrication

Market research on the availability of a two-roller rolling machine that would suit the authors needs was conducted in South Africa. It was found that many companies supply three-roller rolling machines. Research was then conducted outside South Africa, and it was discovered that the two-roller rolling machines available are too expensive. Therefore, the authors decided to design and fabricate a machine to suit their needs. Information was sourced from various literature, and ideas were gathered and evaluated based on their needs. The design was done using Autodesk Inventor Professional 2016 software (see figure 1 for the drawing). The design was fabricated by one of the authors at a manufacturing workshop at the University of South Africa's Florida Campus.

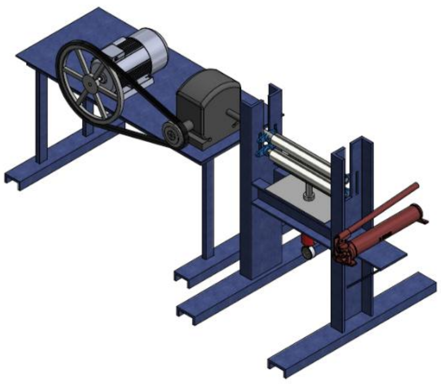

Figure 1: Drawing of the two-roller rolling machine

2.2 Components

2.2.1 Frame material selection

A frame is an engineering structure of different shapes and sizes, a combination of beams and columns. The frame needed to be strong to withstand the load, vibration and pressure. Therefore, material selection was critical. The material needed to be readily available, strong, easy to weld and inexpensive. Steel and aluminium were considered, but steel was chosen as the most suitable alternative.

2.2.2 Electric motor

The interaction between the magnetic fields set up in the stators and rotor windings transforms electrical energy into mechanical energy in a motor. Induction motors, direct current motors, and synchronous motors are the three types of electric motors. A stator, a rotor, bearings, and a frame are common operating components in all motor types. The most appropriate motor for this design was a 3-kW and 1450 rpm speed.

2.2.3 Reduction gearbox

A speed reduction gearbox is a mechanical system of gears and shafts that reduces the input shaft's rotational speed in order to slow the output shaft's rotational speed, thus increasing the system's torque. A single reduction gearbox with an input speed of 457 rpm and an output speed of 30.9 rpm is used in this configuration.

2.2.4 Bearings

A bearing is a machine component that supports another moving machine component and allows relative motion between the members' contact surfaces when holding the load [17]. Pillow block bearings are used in this design. The housing is made of cast steel, which offers greater strength and shock resistance.

2.2.5 Rollers

The rolling machine has two rollers – an upper and a lower roller. The lower roller can move up and down to apply pressure on the material fed in between the rollers. Each roller is supported on both sides by a pillow block bearing. The upper roller is fixed at one position and is connected to the gearbox output shaft by the coupling. The material is fed in between the rollers and the lower roller is pushed up by the hydraulic jack to apply pressure on the material being rolled. The rollers are made of mild steel material. The roller can rotate at three different speeds, namely 9, 18 and 36 rpm.

2.2.6 Hydraulic jack

Hydraulic jacks have been used extensively in the maintenance, servicing and repair of motor vehicles [18]. In this design, a 12-ton hydraulic jack is used to lift the lower roller to apply pressure on the material being rolled.

2.2.7 Pulley

For hundreds of years, belt-pulley drives have been commonly used to transfer power. Friction between the belt and the pulleys transmits power from the driver pulley to the driven pulleys [19]. Belt-drive systems are used as an effective means for transmission of power and are found in various applications, including conveyors, machine tools, stationary or mobile-powered rotating equipment [20]. In this design, a pulley of 100 mm is mounted on the output shaft of the AC motor by a tapered lock bush. Pulleys of 100, 200 or 400 mm can be mounted on the input shaft of the reduction gearbox depending on the speed required.

2.3 ARB experiment

Aluminium (Al 1050-H4) with dimensions of 100 mm x 25 mm x 0.9 mm was used in the ARB application. The rollers were aligned by running a filler gauge across them to ensure that the distance between them was consistent. The material was put between the rollers and a 3-ton pressure was applied to the rolled material. The samples were pushed through the rollers on the first pass during the deformation process. At speeds of 9, 18, and 36 rpm, three samples were rolled once each. Figure 2 depicts the manufactured rolling machine. The sample was grasped by the two horizontal shafts, which pushed it through the rollers. Before and after the pass, the thickness was measured with a Vernier calliper.

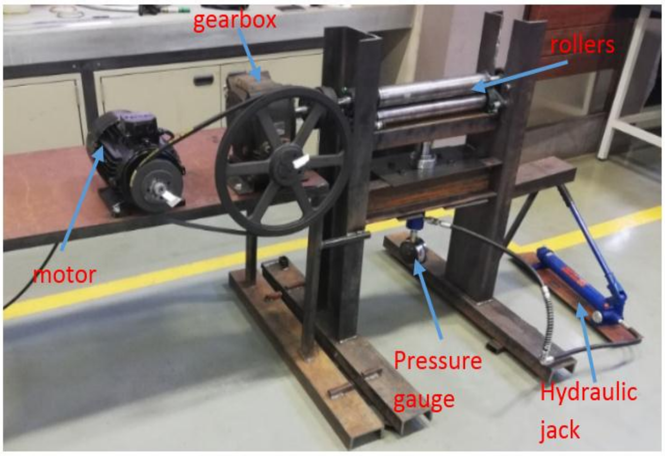

Figure 2: Rolling machine

2.4 Vickers microhardness test experiment

Vickers micro-scales are also known as micro-indentation scales since the indents are so small and they must be measured with a high-powered microscope. The test forces on these scales range from 1 g to 1 000 g. Before the microhardness test, samples were cut on the rolling direction and mounted. In this experiment, the ASTM E384 test method was used. Five indentations were made at various locations per sample for statistical consideration. The Dura Vision tester from EMCO was used in this experiment. For this experiment, the test force was 1 kg for all samples and 10 seconds load-holding time.

3. RESULTS AND DISCUSSION

3.1 Design and fabrication

Channel iron of 38 by 38 mm of different lengths was used to make the frame. Square tubes of 20 by 20 mm and a flat sheet of 2 mm thickness were used to make a table on which the 3-kW electric motor and the reduction gearbox were mounted. Two rollers, each 300 mm long and with a diameter of 70 mm, were machined from mild steel on a lathe machine. The electric motor and reduction gearbox were connected by a V-belt. The output shaft of the reduction gearbox and the upper roller were connected by a coupling. The upper roller was fixed in one position while a hydraulic jack of 12 ton allowed the lower roller to move up and down. A pressure gauge was connected to the hydraulic jack. The material to be rolled was placed in between the rollers and the hydraulic jack was pumped to push the lower roller up until the required pressure was reached between the rollers and the material. The machine was then switched on to start the rolling process. The relationship between pully size and rolling speed is presented in table I.

3.2 Relationship between pulley size and rolling speed

Table I: Relationship between pulley size and rolling speed

Pulley size (mm)	Rolling speed (rpm)
400	9
200	18
100	36

Table I shows the three speeds at which the machine can operate. The motor pulley and reduction gearbox pulley were connected by the V-belt. The output shaft of the reduction gearbox and the upper roller were connected by the coupling. The 400 mm diameter pulley, which was connected to the reduction gearbox input shaft, resulted in a roller speed of 9 rpm. When the pulley size changed to 200 mm, the roller speed doubled to 18 rpm. When the pulley size on the reduction gearbox input shaft was reduced to 100mm, the speed increased three-fold to 36 rpm. The machine can operate at three different speeds based on the pulley size connected to the reduction gearbox input shaft. The relationship between thickness reduction and rolling speed is presented in table II.

3.3 Relationship between thickness reduction and rolling speed

Table II: Relationship between thickness reduction and rolling speed.

Thickness reduction (mm)	Rolling speed (rpm)
0.9	0
0.639	9
0.635	18
0.634	36

The results in table II are graphically presented in figure 3.

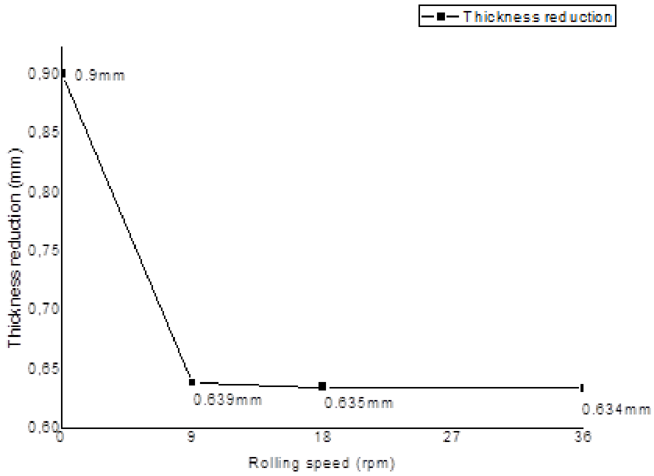

Figure 3: Relationship between rolling speed and thickness reduction

Figure 3 presents the relationship between machine rolling speed and thickness reduction. The results from figure 3 show that there was not much difference in material thickness reduction at all three rolling speeds when the constant applied pressure between the rollers was 3 ton. Thickness reduced from 0.9 mm to 0.64 mm, which is a 29% reduction, when the samples were rolled at 9 and 18 rpm. Material thickness was reduced to 0.63 mm when the rolling speed was 36 rpm, which is the top speed in this design. It was observed that different rolling speeds did not have any effect on the thickness reduction of aluminium 1050-H4. It was not easy to control and handle the rolled material at the maximum speed of 36 rpm. In addition, at top speed the rolled samples did not come out straight. It was easy to control, and handle material being rolled at the lowest speed of 9 rpm. The relationship between microhardness and rolling speed is presented in table III.

3.4 Relationship between microhardness and rolling speed

Table III: Microhardness experiment results

Number of measurements	0 rpm	9 rpm	18 rpm	36 rpm
1	40.75	45.09	49.98	48.99
2	40.21	45.77	47.28	49.7
3	39.91	45.31	48.2	48.8
4	40.14	45.44	47.95	49.21
5	40.56	43.28	48.33	48.13
Average	40.3	45	48.3	49

The results in table III are graphically presented in figure 4.

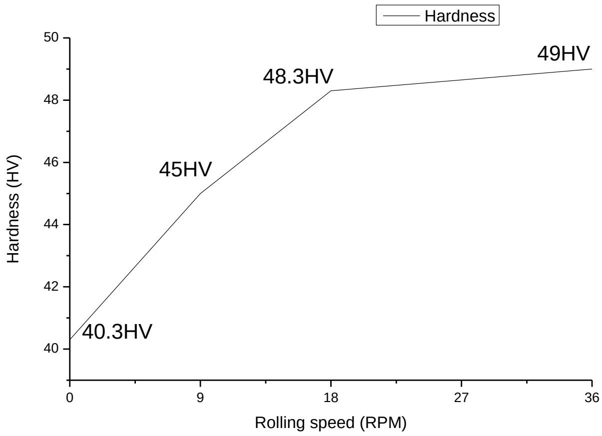

Figure 4: Average hardness (HV 0.1) at different rolling speeds

Five indentations were made per sample at different locations during the microhardness test of aluminium 1050-H4 alloy to ensure repeatability of performance. The changes in the Vickers microhardness test as a function of rolling speed are shown in Table III. The parent sample, which is a sample of material before it is rolled, was found to be the softest, with an average hardness of 40.3 HV. The material became harder when the rolling speed increased. Maximum hardness was noticed at the top speed of 36 rpm and hardness was reported to be 49 HV. The higher rolling speed enhanced material hardness.

4. CONCLUSION

The authors were able to design and manufacture a three-speed, two-roller rolling machine, which is affordable and easy to operate and maintain. The machine was designed to perform accumulative roll-bonding experiments. It can be operated at three different speeds depending on the needs of the user. It was designed mainly to reduce the thickness of aluminium strips. The maximum thickness the machine can handle is 1.6 mm aluminium flat plate. It was found that the machine is not easy to control or to take measurements such as the material surface temperature at maximum rolling speed. The results show that there is no difference on the thickness reduction of aluminium 1050-H4 at different speeds. The hardness of material increases when the rolling speed increases. It can be concluded that a change in rolling speed does not influence the reduction of the material's thickness when applied pressure between the rollers is constant. However, the increase in rolling speed enhances mechanical property (hardness).

ACKNOWLEDGMENT

The authors acknowledge the technical support of Mr L. Lebea and Mr S. Motloung. They would also like to thank the University of South Africa and the University of Johannesburg for financial support.

REFERENCES

[1] A. Biswas, I. S. Bayer, A. S. Biris, T. Wang, E. Dervishi, and F. Faupel, "Advances in top-down and bottom-up surface nanofabrication: Techniques, applications & future prospects," *Adv. Colloid Interface Sci.*, vol. 170, no. 1–2, pp. 2–27, 2012.

[2] A. Nentwich, "Production of nanoparticles and nanomaterials," *Planet-Austria.At*, vol. 6, no. June 2014, pp. 1–4, 2011.

[3] Irina Hussainova, "Techniques for Synthesis of Nanomaterials," no. I, pp. 1–40, 2014.

[4] D. Brabazon *et al.*, "Commercialization of nanotechnologies-A case study approach," *Springer Int. Publ.*, pp. 1–315, 2017.

[5] Y. Ivanisenko *et al.*, "High Pressure Torsion Extrusion as a new severe plastic deformation process," *Mater. Sci. Eng. A*, vol. 664, pp. 247–256, 2016.

[6] J. KuÅ›nierz and J. Bogucka, "Accumulative roll-bonding (ARB) of A199.8%," *Archives of Metallurgy and Materials*, vol. 50, no. 1. pp. 219–230, 2005.

[7] P. Chen, "Design and Analysis of Portable Rolling and Bending Machine Using CAD and FEA tool," *Int. J. Eng. Res. Technol.*, vol. 2, no. 3, pp. 1–10, 2013.

[8] M. Gadekar, A. Student, and A. Prof, "Design & Development of Three Roller Sheet Bending Machine," *Int. J. Recent Innov. Trends Comput. Commun.*, vol. 3, no. 8, pp. 5132–5135, 2015.

[9] R. S. Bello, "Development and evaluation of metal rolling machine for small-scale manufacturers," *Agric. Eng. Int. CIGR J.*, vol. 15, no. 3, pp. 80–85, 2013.

[10] J. Duhovnik, I. Demsar, P. Drešar, J. Duhovnik, I. Demšar, and P. Drešar, "Sheet-Metal Bending," *Sp. Model. with SolidWorks NX*, vol. 2, no. 3, pp. 297–334, 2015.

[11] P. Vishwakarma, "Design and Analysis of M . S Roller in Sheet Metal Rolling Machine," *Int. J. Eng. Res. Gen. Sci.*, vol. 4, no. 2, pp. 192–195, 2016.

[12] E. E. LEVI, "Vickers Hardness Test - eBook," *Pract. Hardness Test.*, pp. 8–9, 2003.

[13] J. Petrík, "On the Load Dependence of Micro-Hardness Measurements: Analysis of Data by Different Models and Evaluation of Measurement Errors," *Arch. Metall. Mater.*, vol. 61, no. 4, pp. 1819–1824, 2016.

[14] Z. Roell, "Vickers Hardness Test," *Indentec Hardness Test. Mach. Ltd.*, pp. 8–9, 2011.

[15] M. Gasko and G. Rosenberg, "Correlation between hardness and tensile properties in ultra-high strength dual phase steels," *Mater. Eng. …*, vol. 18, pp. 155–159, 2011.

[16] C. Chuenarrom, P. Benjakul, and P. Daosodsai, "Effect of indentation load and time on knoop and vickers microhardness tests for enamel and dentin," *Mater. Res.*, vol. 12, no. 4, pp. 473–476, 2010.

[17] S. U. Gunjal, "A study of bearing and its types," *Int. J. Adv. Reseach Sci. Eng.*, vol. 4, no. October, 2015.

[18] S. K. Amedorme, Y. Fiagbe, S. K. Amedorme, and Y. A. K. Fiagbe, "Modification of an Existing Small Hydraulic Jack for Lifting Light Duty Vehicle Plasma Gasification of Municipal Solid Waste (MSW) for Energy generation View project Modification of an Existing Small Hydraulic Jack for Lifting Light Duty Vehicle," *Int. J. Sci. Technol.*, vol. 5, no. 11, pp. 552–557, 2016.

[19] L. Kong and R. G. Parker, "Steady mechanics of belt-pulley systems," *J. Appl. Mech. Trans. ASME*, vol. 72, no. 1, pp. 25–34, 2005.

[20] S. Chowdhury and R. K. Yedavalli, "Dynamics of belt-pulley-shaft systems," *Mech. Mach. Theory*, vol. 98, no. April 2016, pp. 199–215, 2016.