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Characterising Effects of Applied Loads on the Mechanical Properties of Formed Steel Sheets

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Abstract**—**The purpose of this research study is to investigate the manner in which various loads affect the mechanical properties of the formed mild steel plates. The investigation focuses on examining the cross-sectional area of the metal plate at the centre of the formed mild steel plate. Six mild steel plates were deformed with different loads. The loads applied on the plates had a magnitude of 5kg, 10kg, 15kg, 20kg, 25kg and 30kg. The radius of the punching die was 120mm and the loads were applied at room temperature. The investigations establishedthat the applied load causes the Vickers microhardness at the cross-sectional area of the plate to increase due to strain hardening. Hence, the percentage increase of the hardness due to the load was found to be directly proportional to the increase in the load. Furthermore, the tensile test results for the parent material showed that the average Ultimate Tensile Strength (UTS) for the three samples was 308 MPa while the average Yield Strength and Percentage Elongation were 227 MPa and 38 % respectively. Similarly, the UTS of the formed components increased after the deformation of the plate, as such it can be concluded that the forming loads alter the mechanical properties of the materials by improving and strengthening the material properties.

Keywords**—**Applied load, forming, mechanical properties.

I. INTRODUCTION

METAL forming is a crucial aspect in a manufacturing process to obtain a finished product. Metal bending and forming is one of the metal forming techniques employed in the manufacturing industry.Cutting and forming operations are sheet metalworking processes performed on thin metal sheets. The metal sheets usually have a thickness of between 0.4mm and 6mm. Sheet metals which have a thickness greater than 6mm are called plates, while sheet metals which have a thickness less than 6 mm are called sheets. Sheet metalworking has a vital commercial value, considering the number of industrial products that involve parts from sheet or plate metals. There are a number of industrial products that make use of sheet and plate metals, these include among many; truck and car bodies, locomotives, railway cars, airplanes, construction equipment and appliances [1]. In particular, the metal bending and forming techniques is commonly used in the automobile industry where metal sheets are bent to a particular angle or curvature of specific geometry and dimensions. The metal bending technique is a processthat involves exerting a specific load on the upper die which presses into the clamped sheet of metal into the lower die creating a component with specific shape geometry. However, when the exerted load is removed and the component is taken out of the die, the component tends to change from the required geometry. This change of the component from the intended geometry is known as springback [2]. The springback phenomenon may render components to be useless due to the alteration of geometry and dimensions of the component. Therefore, it is crucial to control and minimise the springback of manufactured components. Moreover, the springback in high strength steel plates is significantly high due to the high yield strength of the material [3]. A typical schematic of the mechanical forming process is shown in Fig. 1.

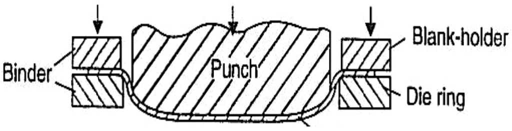

Fig. 1 Schematic of Mechanical forming process [4]

Springback as a phenomenon that occurs during mechanical forming process has a major influence in the quality and performance of a component. It may be defined as geometrical and dimensional changes that occur in component after a part has been unloaded. The springback phenomenon is attributed to the elastic recovery that took place in the formed material after being unloaded. [5]. The springback largely depends on the material properties of metals, in particular the stress- strain characteristics of a metal. Knowing the yield point of the material helps to determine the stress required to surpass the elastic region of a sheet. This is important so that plastic deformation can be achieved during the bending procedure. The stress applied to the sheet during the bending process is related to the bending parameters such as the punch load (N) and the punch stroke (mm) [6].

Steel is the most used engineering material in the manufacturing industry due to the availability, versatility, properties and economic advantages that steel has compared to other engineering materials. As such, mild steel plate is considered for this research investigation. Several research work has been conducted in the area of behaviour of formed components; one of such was reported of Kouznetsova *et al.*, [7], they investigated the mechanical behaviour of metastable austenitic steels in pure bending. The investigation showed that the quantity of springback of Sandvik Nanoflex was greater than that of non-transforming materials. This experiment showed that the springback behaviour in

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metastable austenitic steel is different from the non-transforming steels. Similarly, Huang and Leu [8] investigated the variables involved in ‘V’ die bending of steel sheets. The variables investigated are the punch radius, the punch width, the punch speed, the die radius, the coefficient of friction (lubrication conditions), and the normal anisotropy. The study was carried experimentally and using an elastic-plastic Finite Element (FE) analysis to model the ‘V’ bending process. The result of the Finite element analysis conducted showed that the applied load changed with punch stroke until the bend flange of the metal sheet is in line with the die surface. Furthermore, the experimental results showed that the applied load changes with punch stroke until the bend flange of the metal sheet is in line with the die surface. Also, the punch load increases rapidly when the coining process occurs at the end stage of the bending procedure, decrease in the coefficient of friction and when the punch radius increases. Shabara *et al.*, [9] also developed a numerical model to study the effect of material properties on forming loads, product geometry, springback and residual stresses. They used computer aided design and manufacturing software to model the stretch bend process. The results from the numerical model developed for steel and aluminum showed the springback magnitude relies significantly on the tensile force during the stretch bend process.

Furthermore, Liu *et al.*, [10] investigated the deformation behavior of mild steel. The investigation entailed the heating of a rectangular plate to a temperature of 873K at a rate of 10K/s for a period of 1800s. After the completion of the rolling process, the specimen was cooled by water quenching. It was observed in the warm deformed specimen that the grain boundaries of the grains were cluttered, thus suggesting the presence of sub-grains boundaries. The grains that resulted due to the warm rolling were more or less equiaxed. The pearlite grains observed in the parent material were not noticed in the warm rolled specimen. The hardness results showed an increase in the microhardness of the material after warm deformation. The hardness of the parent material was measured to be 220 HV. The hardness value after deformation was 300 HV at the centre of the specimen and 340 HV near the surface of the specimen. Other mechanical properties that were improved by the warm deformation include the ultimate tensile strength (from 550 MPa to 800 MPa) and the yield strength (from 230 MPa to 700 MPa). Hence, it can be concluded that the ferrite grain perfectly recovered from the warm deformation. The ferrite grains were almost equiaxed. Also, the warm deformation improved the mechanical properties of the material. The high hardness near the surface indicates an increase in the wear resistance of the material.The work of Shin *et al.*, [11] on the effect of equal channel angular pressing on the microstructure and mechanical properties of low carbon steel was reported in the literature. They used a cylindrical sample heated to a temperature of 623 K for the experiment and investigated the tensile, microstructural properties and the hardness of the processed sample. The results of the optical microstructure showed that the microstructure of the sample changed after every pass. The microstructure was severely elongated after an odd number of pass.

In addition, the microstructure of the sample was equiaxed after an even number of passes. The microhardness test results showed that the hardness of the sample increased with every single pass. Furthermore, the increase in hardness was significant after the first pass. However, the increase in hardness was less substantial for the rest of the equal channel angular pressing. The work of Shin *et al*., [11] showed that there is a correlation between the microstructural evolution and the change in hardness of the low carbon sample. The microstructural results showed that the grain refinement was very noticeable after the first pass, while the hardness of the sample increased by a large amount after the first pass. Also, the change in microstructure and hardness of the sample was less significant for further passes. It is important to gain an understanding on the impact of loading a material undergoes during mechanical forming. The process of mechanical forming of a metal sheet may alter the mechanical properties of the material. In this investigation, an experimental method was conducted to determine the effect of varying loads on the mechanical properties of mild steel sheets.

II. EXPERIMENTAL SET UP

The test samples were made from mild steel sheets with dimensions of 200x50 x 1mm^3. The mechanical bending process was carried out on a 20 ton capacity mechanical press. It consists of an upper tool called the punch and a lower tool called the die, between which the sheet metal is located. Both the upper and the lower die were designated and fabricated from H13 tool steel specifically for the purpose of this research. The sample was carefully positioned and clamped in between the two ends of the lower die and held in place by the clamp before being stretched by impact of the force of the upper die on the clamped sample under the power of a hydraulic ram. The two clamping lower dies were made adjustable to allow the formed samples align with the lower die when the upper die is forcefully lowered into it. Clamping of the sheet was along the width of the workpiece so that stretching can occur over the length thereby promoting shrinkage across the width. Fig. 2 shows the experimental set-up of the mechanical bending.

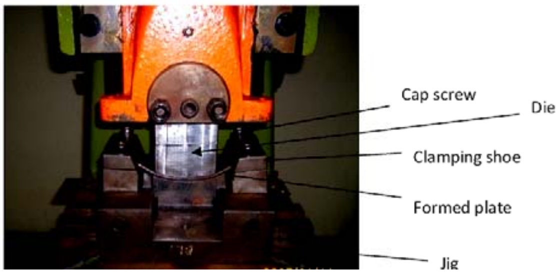

Fig. 2 Experimental set-up for mechanical bending process

Six mild steel samples were deformed with different loads. The specific loads applied on the plates were 5kg, 10kg, 15kg, 20kg, 25kg and 30kg. The radius of the bending die was 120mm and the loads were applied at room temperature. The final geometry of the bent sheet was not similar to the geometry of the plate during the forming process. Thus, the sheet material elastically recovered after the removal of the load. The final radius of the deformed plate was compared to the radius of curvature of the punch to determine the amount of spring back that took place. Each sample was applied with the specific loads and after unloading the springback percentage was measured.The tensile samples were produced from the parent materials and tested in accordance with ASTM E-8 standard. A servo-hydraulic Instron 8801 tensile testing machine was used to conduct the tests. An extension rate of 5 mm/min and a gauge length of 50 mm were used. The Vickers micro hardness of the cross sections of the samples were taken using model MH-3 microhardness indenter with a load of 300g and a dwell time of 15 seconds. The indentations were taken at an interval of 2 mm, with all the indentations manually focused and read to ensure that all measurements were made on the specimen and not on the polyfast [material used to mount the specimen]. All the measurements were taken in the as polished condition.

III. RESULT AND DISCUSSION

A. Percentage Change in Radius Due to Applied Load

The radius of curvature of the punch was 120mm but each formed mild steel plate attained a specific radius of curvature after the removal of the forming load. This attained curvatures were calculated using Equation (1), this is based on simple mathematical geometry. The springback percentage was calculated using the radius of curvature of the bending die.

$$R = \frac{h}{2} + \frac{S^2}{8h} \tag{1}$$

where;
R is the radius of curvature.
h is the perpendicular height from the midpoint of the curvature to the midpoint of measured length s.
S is the measured length between the two ends of the formed sheet.

The formed steel sheet is schematically illustrated in Fig. 3.

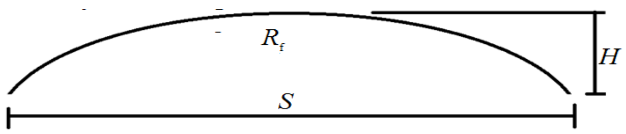

Fig. 3 Schematic showing the parameters for calculating the radius of curvature

The measured radius of curvature after unloading and the calculated percentage change in the radii is presented Table I.

TABLE I
RESULTS OF MEASURED CURVATURES

Applied Loads (L) kgf	Curvature R (mm)	Percentage changein radii (%)
5	186.5	55.4
10	182	51.7
15	177	47.5
20	175	45.8
25	165	37.5
30	160.2	33.5

The results of the investigation showed that the radius of curvature of the mild steel sheets after unloading decreases with an increasing applied loads. Thus, the results indicated that the springback percentage of the plate decreases when the applied load is increased. The relationship between the springback percentage and the applied load is inversely proportional. The work reported by Panthi *et al*., [12] was in agreement with the result of the research investigation. They found that there exists an inverse relationship between applied load and the springback. The springback percentage decrease as the applied load increases thus, the linear influence of loads on the springback percentage increases until a saturation point. From the experimental result presented in Table I, the effect of load on the radius of curvature showed that as the load increases, the radius of curvature increases, this implies that more force is required to deform the plate to have smaller radius of curvature and similarly, the percentage change also follows the same pattern. This is further illustrated with the graph of the applied load against both the springback and the radius of curvature shown in Fig. 4.

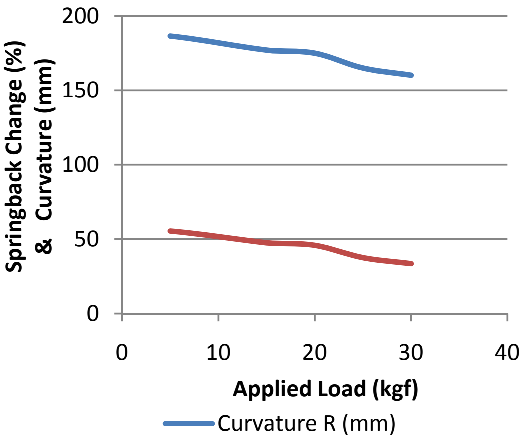

Fig. 4 Plot of applied load against springback and curvature

B. Vickers Microhardness

Seven indentations were taken for each of the formed sample being investigated. The results of the average Vickers microhardness for each sample with the percentage increase in the hardness value compared to the parent material is presented in Table II and the graphical representation is shown in Fig. 5.

TABLE II
VICKERS MICROHARDNESS MEASUREMENT

Depth (mm)	Parent Material	Applied Load (Kgf)					
		5	10	15	20	25	30
2	33	33	34	35	36	37	39
4	33	33	34	35	37	38	39
6	32	33	35	36	37	38	40
8	32	34	35	36	37	38	40
10	32	34	35	36	37	38	40
12	33	34	34	36	37	38	40
14	33	34	34	37	38	38	42
Ave HV	32.6	33.6	34.4	35.9	37	37.9	40
% Increase	-	3.1	5.7	10.1	13.6	16.2	22.8

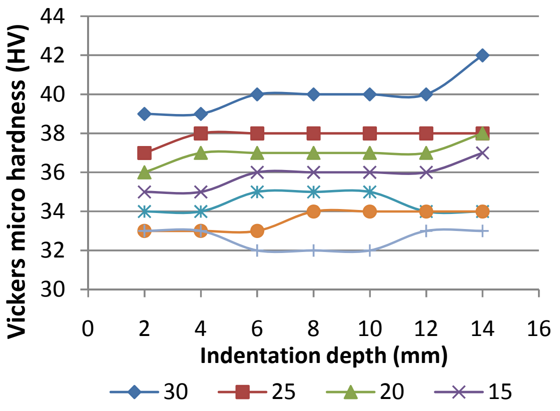

Fig. 5 Plots of Vickers microhardness against depth

It was observed from the investigations that the applied load causes the hardness across the sectional area of the plate to increase and as such the percentage increase in the microhardness values due to the applied load is directly proportional to the increased load, this is shown in Fig. 6.

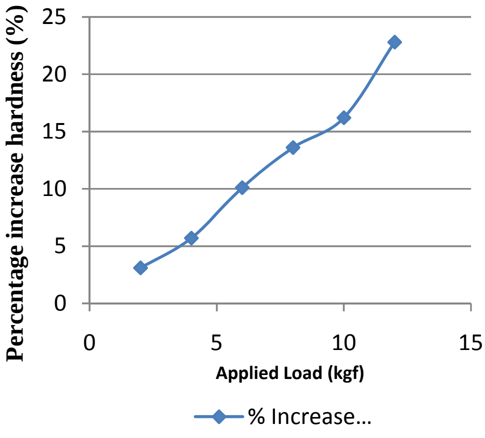

Fig. 6 Graph of applied load against hardness

C. Tensile Testing of the Parent Material

The tensile test was conducted for three samples and the summary of the tensile test results for the parent material is presented in Table III and the stress – strain graph is also shown in Fig. 7.

TABLE III
SUMMARY OF TENSILE TEST RESULT FOR PARENT MATERIAL

Test Samples	Y S (MPa)	UTS (MPa)	% Elongation
1	230	308	35.55
2	220	307	42
3	230	308	38
Mean	226.7	307.7	38.5

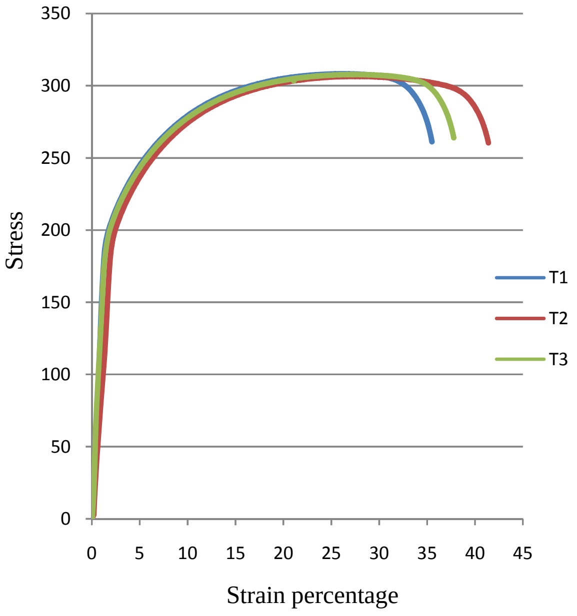

Fig. 7 Stress – Strain Curve

The tensile test results showed that the average Ultimate Tensile Strength (UTS) for the three samples was 308 MPa while the average Yield Strength and Percentage Elongation were 227 MPa and 38 % respectively.

D. Ultimate Tensile Strength for Formed Sample

The Ultimate Tensile Strength (UTS) for each of the formed plates were calculated based on the measured Vickers microhardness of the six set of formed samples.The relationship between the UTS and Vickers microhardness is expressed by Equation 2, as reported by Akinlabi *et al*., [13].

The average UTS was therefore used to determine the change in the UTS of the formed samples.

$$UTS = 9.81\left[\frac{H}{2.9}\right]\left[\frac{n}{0.217}\right]^{n} \tag{2}$$

where,
H= Vickers microhardness

N =Strain hardening index, (n=0.21 for low carbon steel – annealed).

The calculated UTS for the formed samples and the percentage change in the UTS are presented in Table IV.

TABLE IV
UTS VALUES FOR FORMED SAMPLES

Load (Kg)	Average HV	UTS (MPa)	% change in UTS
PM	32.6	109.4	-
5	33.6	112.8	3.1
10	34.4	115.7	5.7
15	35.9	120.5	10.1
20	37.0	124.3	13.6
25	37.9	127.2	16.2
30	40.0	134.4	22.8

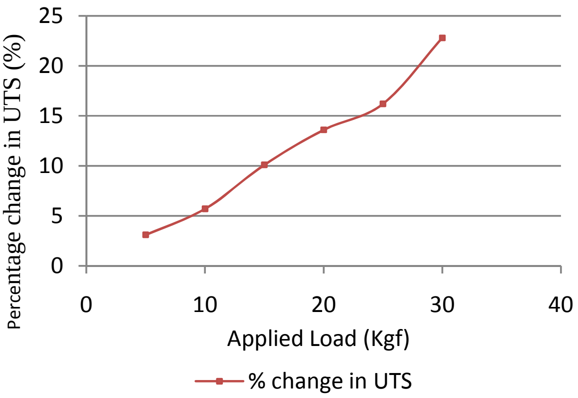

Fig. 8 Graph of percentage change in UTS

The plot of applied loads against the percentage change in the UTS showed a progressive direct relationship. This implies that the UTS of the material increases after the deformation of the sheets, as such it can be concluded that the forming loads are able to alter the mechanical properties of the materials by improving and strengthening the material properties.

IV. CONCLUSION

The effects of varying loads on the mechanical properties of mild steel sheets have been presented and discussed. The linear and inversely proportional relationship between the springback and the load makes it possible to predict the springback percentage of the mild steel sheets for the load range used in this investigation. Furthermore, the springback percentage may be significantly reduced when loads of larger magnitudes are applied. However, the investigation was only limited to a maximum forming load of 30 kg. The hardness of the material improved after the loading the process. The change in the hardness of the material and forming load showed a linear relationship, this implies that the forming loads are able to alter the mechanical properties of the material. Also, the increase in the hardness of the material due to the load showed that forming loads improve the mechanical properties of the material. Furthermore, the Ultimate Tensile Strength (UTS) of the material calculated from the Vickers hardness value increased with an increase in the forming load.

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REFERENCES

[1] M. P. Groover, *Fundementals of Modern Manufacturing: Materials, Processes and Systems*, 4th ed. SI Version: John Wiley Sons, Inc, 2011.

[2] M. Samuel, "Experimental and numerical predictions of springback and side wall curl in U-bendings of anisotropic sheet metals," *Journal of Materials Processing Technology*, vol. 105, pp. 382-393, June 2000.

[3] C. Gomes, O. Onipede, and M. Lovell, "Investigation of springback in high strength anistropic steels," *Journal of Materials Processong Technology*, vol. 159, pp. 91-98, 2005.

[4] Sheet metal forming. Available at: www.customerpartnet.com/wu/sheet-metal-forming [Accessed October 2012].

[5] X. An Yang and F. Ruan, "A die design method for springback compensation based on displacement adjustment," *International Journa lof Mechanical Sciences*, vol. 53, pp. 399-406, 2011.

[6] D. S. A. Mkaddem, "Experimental approach and RSM procedure on the examinaion of springback in wiping-die bending processes," *Journal of Materials Processing Technology*, pp. 325-333, Feb 2007.

[7] V.G. Kouznetsova, J. van Beeck, and M.P.F.H.L. van Maris, "The mechanical behaviour of metastable austenitic steels in pure bending," *Materials Science and Engineering A*, vol. 528, pp. 7207-7213, 2011.

[8]]. Y.M. Huang and D.K. Leu, "Effects of process variables on V-die process of steel sheet," *International Journal of Mechanical Science*, vol. 40, pp. 631-650, 1998.

[9] M.A.N. Shabara, M.D. Al-Ansary, and A.A. El-Domiaty, "Determantion of stretch-bendability of sheet-metals," *International Journal of Machining Tools Manufacturing*, vol. 36, pp. 635-650, 1996.

[10] M. Lui et al., "A submicron mild steel produced by simple warm deformation," *Materials and Engineering A*, vol. 360, pp. 101-106, 2003.

[11] D.H. Shin, C.W. Seo, J Kim, K.T. Park, and W.Y. Choo, "microstructures and mechanical properties of equal-channel angular pressed low carbon steel," *Scipta Materialia*, vol. 42, pp. 695-699, 2000.

[12] S.K. Panthi, N. Ramakrishnan, R. Das Gupta, and J.S. Chouhan, "Study Of Effect Of Load On Springback In Sheet Metal Bending," *Trans. Indian Inst. Met.*, vol. 61, pp. 39-43, February 2008.

[13] S. Akinlabi, M. Shukla, E. Akinlabi, and M. Tshilidzi, "Laser beam forming of 3mm steel plate and the evolving properties," *World Academy of Science, Engineering and Technology*, vol. 59, 2011.