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Shifting of the neutral line at a v-bending process of AISI 1015 steel plate

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Abstract. During a forming process of steel plate microstructural changes occurs in the material. The outside part of the material experiences tension while compression stress takes place in the inner side. Constant uniaxial load, speed and temperature were applied on the V bending of 4 mm thick low carbon steel plate. Microstructural observation and hardness test were carried out on the cross-section area of the plate to assess the changes within the material. It is revealed that an offset of the imaginary neutral line to the inner side has occurred. The elongation of stretched material on the outer side, which is associated with microstructural changes of grain shape, orientation and hardness value does not exceed the proportional plastic area.

1. Introduction

1.1. Deformation in the bending process

V bending is one of the most common forming technologies that is applicable in sheet metal forming. In V bending processes the sheet material was cut in angles of 0°, 45° and 90° throughout the rolling direction. and the obtained spring-back and -go amounts were examined after the bending process [1]. The effect of material thickness on bending processes was reported in previous studies [2].

1.2. Stress state

The influence of plate thickness has been observed. Stress state determination numerical analysis during the bending process was applied by using. SimufactForming v10 program package [3]. It was found that there is no significant difference in values of stress for different sheet thicknesses. Figure 1 shows the stress state of plate for various thickness.

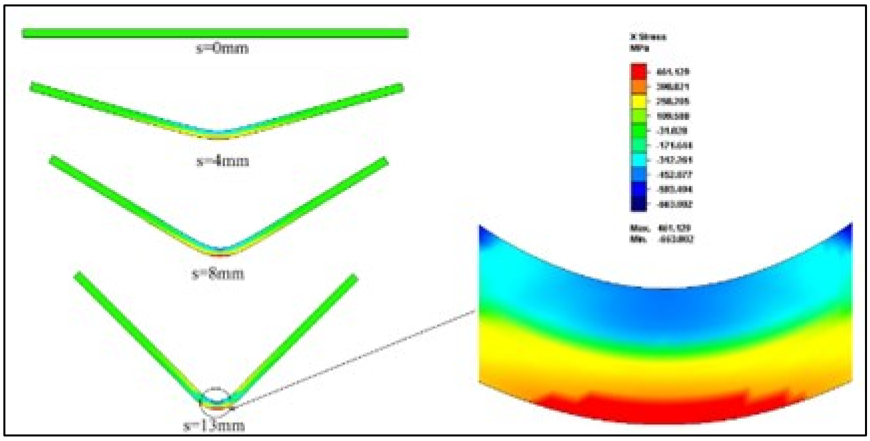

Figure 1. Stress state for different thickness [3].

1.3. Grain deformation

Microstructural characterization and deformation of X10CrAlSi24 Sheet Material by applying V-Bending process has been carried out [4]. It was observed that at 4 mm thick steel plate the increased bending angle had remarkable effect o, the grain orientation and crack that might be occured. The grain orientation is mostly tangential to the center of the bending radii.

1.4. Grain size, orientation and its influence to the mechanical properties

The hardness is mainly governed by the average grain size and is independent of the grain shape or the grain aspect ratio. The ductility (in terms of the reduction in area) is influenced by the grain aspect ratio. In contrast, the ultimate tensile strength is independent of the grain aspect ratio but shows an explicit dependency on the specimen orientation [5]. The change in grain size accompanies a plastic deformation determines the change in strength of a polycrystalline material as shown in Hall and Petch's equation. The equation shows an increase in strength by decreasing the grain diameter. Hardness itself is defined as the ability of a material to resist against the penetration of other harder objects and its measurement is based on plastic deformation experienced by the material.

When a quasi-static deformation occur, the mechanical properties are controlled by processing parameters (strain, strain rate, deformation temperature and cooling rate). The level of grain size modification does not cause any significant deviations in material behavior comparing to coarsegrained microstructures [6].

2. Design of experiment

2.1. Material

For the purposes of this study low carbon steel plates AISI 1015 with the size of 200mm length, 20 mm width and 4 mm thick were used. Table 1 describes the chemical composition of the material.

Table 1. Elemental composition of sample.

Material	Elements in weight %								
	C	Si	Mn	Cr	Ni	Mo	P	S	other
Low	0.12	0.03	0.56	-	-	-	0.007	0.005	-

2.2. Initial microstructure and normalizing condition

The initial material has inhomogenous grain shape, grain orientation and grain size, which might cause any distortion. Normalizing is carried out on the material to homogenize the microstructure and eliminating stresses caused by the previous rolling process. The material is heated up to 900°C and followed by air cooling.

2.3. Speed and temperature of bending

Since Cracks can evenly be distributed all over the surface of plates and are oriented in the rolling direction and in most cases cracks are fully filled with an iron oxide [7]. Steel plate has therefore to be grinded to produce a smooth surface and minimize the occurance of crack initiating notch. Bending is carried out on samples with V bending tools to form 90° plate. The bending process is done at constant speed of 120 mm.s^{-1} and ambient temperature of 23°C.

2.4. Measuring the strain

Prior to the bending process samples are marked at 4 positions as described in the figure 2. The distance b is equal to one eighth of the inner circumference, which corresponds to 45° of bending. Two lines are marked within b in a similar distance, so that three bands are obtained. The elongation after completion of the bending is determined by calculating the difference between the final distance of strips and the initial distance. The elongation value is then compared and analysed with the tensile diagram of the material.

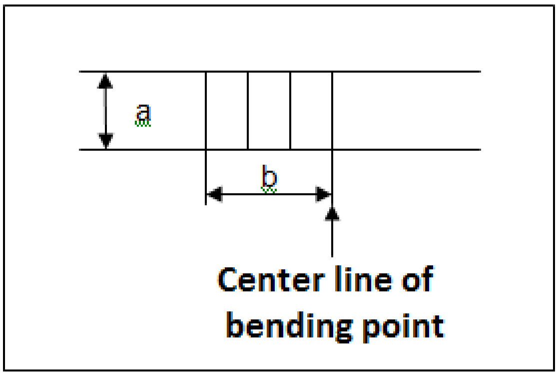

Figure 2. Marking line of samples.

2.5. Measuring the hardness

Hardness test is carried out at several position along the marking lines I to IV Microvickers hardness testing as per ASTM E-384 is considered the suitable method for analysing the mechanical properties of material. Small load of the test enables the measurement of two indentation at a closer distance. For materials in which plastic deformation is predominant, the influence of the load on the measured value of micro-hardness is statistically significant. The relationship between applied load and microhardness manifests reverse Indentation Size Effect (ISE) for all annealing temperatures [8]. Along with the observation of microstructure and elongation value, hardness value indicates a change of material properties due to the bending process.

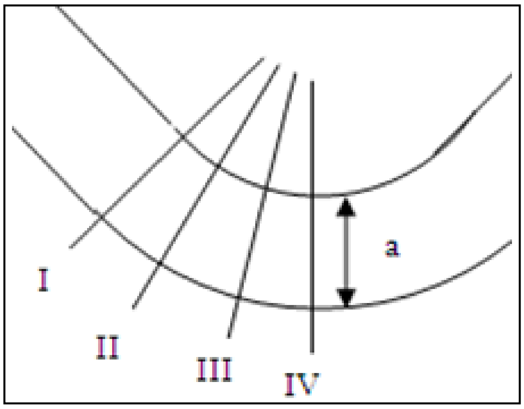

Figure 3. Area of observation.

2.6. *Microstructural observation*

Microstructural test consists of testing of grain shapes, grain orientation and grain dimension. Grain shape is determined by the shape factor resulting from the ratio of two perpendicular diagonal. Grain orientation described the angle between the longer diagonal of grain and the center line. A study on the microstructure evolution of mechanically formed samples under varying load conditions has been reported [9]. It concluded that the grain sizes of the deformed mild steel plate showed elongated grains and it was directly proportional to the applied loads. Finally, the study showed that the grain size elongation and hardness obtained in the deformed samples were linearly dependent on the applied loads. Metallographic examinations are therefore carried out on the pre-determined spots along the lines as described in Figure 3. For this purpose an optical microscope is used on the already prepared samples.

3. Results and discussion

The examination is described in average value for each of the test result.

3.1. *Strain at the inner side and outer side at various position*

Table 2 shows the deformation of the samples which is indicated by the elongation at inner side and outer side of the bending radii. The inner side in general does not experience significant elongation, whereas the outer side is elongated up to 15.9%. The maximum elongation remains nevertheless in the area of proportional plastic deformation.

Table 2. Elongation at the bending radii.

		initial (mm)	final (mm)	elongation %
band I	inner side	7.80	7.82	0.26
	outer side	7.80	8.80	12.82
band II	inner side	7.80	7.82	0.26
	outer side	7.80	8.94	14.62
band III	inner side	7.80	7.80	0.00
	outer side	7.80	9.04	15.90

3.2. *Hardness vickers*

Hardness value of the material at the bending side is described in the Table 3 Compared to the middle part of the cross-section area, the inner side and the outer side of the bending radii show higher value respectively. The Increasing hardness shows that the material has undergone a plastic deformation by using a non linier regression formula, the lowest hardness was calculated. It indicates the lowest internal stress in the material which can furthermore be considered as the neutral area. A neutral line was then then achieved by connecting each point of the lowest state of internal stress.

Table 3. Hardness value at several bending positions.

	Vickers hardness number at various position (HV 0,3)					
	a	b	c	d	e	F
Free Area	205	205	204	204	205	205
Line I	204	206	206	204	204	206
Line II	259	254	233	228	250	260
Line III	266	257	240	240	254	260
Line IV	274	266	268	267	270	276

a. inner side of the bending radii, measured on the surface of sample
b. 0.8 mm from the inner side, measured on the cross section area.
c. 1.6 mm from the inner side, measured on the cross section area.
d. 2.4 mm from the inner side, measured on the cross section area.
e. 3.2 mm from the inner side, measured on the cross section area.
f. outer side of the bending radii, measured on the surface of sample.

3.3. *Microstructural observation*

Figure 4 shows the micrograph of the sample at various positions. During the bending process he outer side of the sample was stretched and experienced therefore tension stress, which is indicated with the elongated grain (flattening of the grain). Figure 4c, 4f and 4i describe the microstructure of the outer side. The grain directions in this side are mostly perpendicular to the centreline. This tensile stress stress after dies displacement is consistent with the previous work by Min Zhang [12], which prooved that the metal farther away from the neutral axis was stressed beyond the yield strength, and plastically or permanently deformed. The micrographs reveal also the differences in grain roughness in the middle and sides of the sample. Microstructure in the middle part of the sample is almost the same as the initial condition prior to the deformation. The grain at the inner side is slightly smaller than the initial condition. The microstructure was composed of ferrite grains and pearlite can be shown in Figure 4.

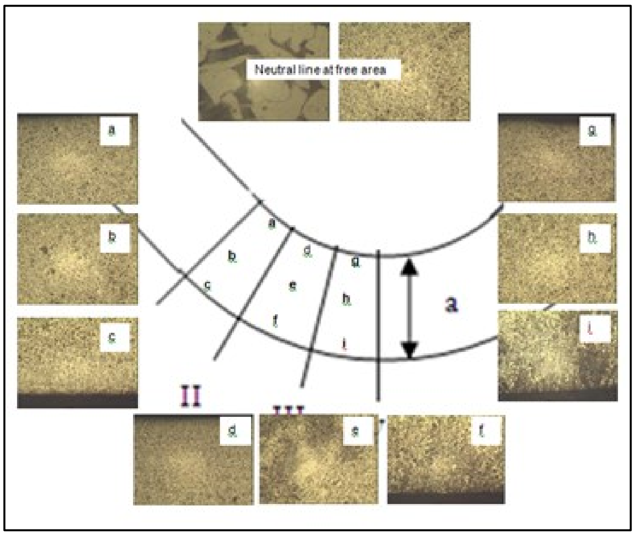

Figure 4. Micrograph of material.

3.4. Discussion

As shown in the Figure 5 the center line of bending (Line IV) exhibit the highest increase of hardness. Higher deformation on this site is considerably the cause of the microstructural change and its mechanical properties. It complies also with the flattened grain of microstructure and its orientation. At the inner side compressive load occures on the material, which produces furthermore slightly smaller grain. The grain orientation is herewith nearly parallel to the centerline of the bending radius.

The result complied with the previous study [10], which declared that mechanical properties of metal strongly depend on the microstructure. The influence becomes more significant with decreasing thickness. The stress at the inner side results in the increase of hardness. The lowest hardness value for each area has been determined and located mostly close to the centerline of sample. Lower hardness value can be considered as lower state of internal stress in the material, which complies in this case with the initial condition of sample and can therefore be determined as the neutral area. However the lowest hardness area shifts slightly to the inner side of bending radii [11].

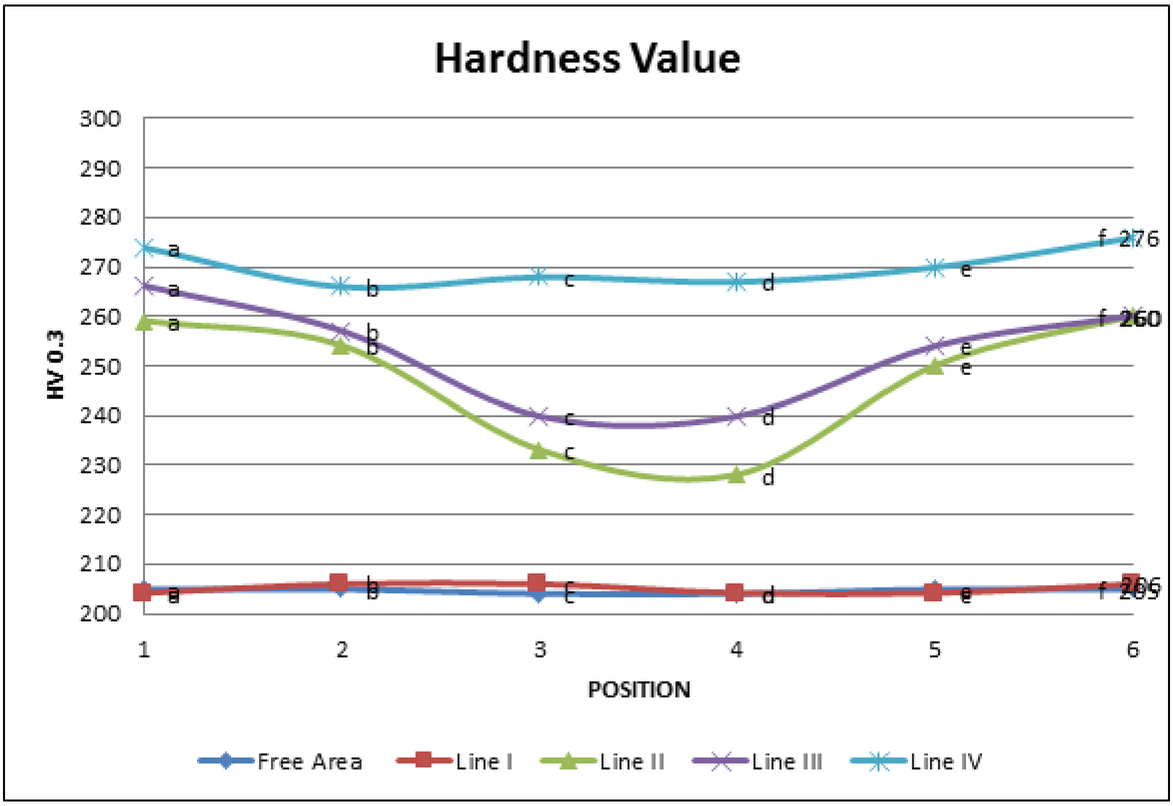

Figure 5. Hardness value in average.

4. Conclusions

The bending process results in plastic deformation due to tension stress on the outside and compression stress on the inside. Grain size,orientation and shape change related to the degree of deformation. Microstructure and properties of the material at crosssection area varies related to the distance to the inner side. The most deformed part (outer side) as indicated by the elongation value shows finer, flattened grain and high hardness value. The neutral line which imaginary connects areas of lowest energy in the cross section area shifts slightly to the center of the bending radius.

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Acknowledgments

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