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The Influence of Lateral Deflection Variations on Wear Properties, Hardness, and Microstructure of Square Hollow Section Steel Resulting from the Bending Process

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ABSTRACT

The bending process is a metal forming process where a metal will be bent with a bending machine and will form like the desired metal (curved). The bending process to make the product requires an external force (deflection). In this final project research there is a goal that is to be able to know the grain size on the specimen, the value of hardness after bending, the value of wear resistance after bending. In the manufacture of specimens using a square hollow steel profile with dimensions of 30 mm x 30 mm with a thickness of 1 mm. the specimen with the highest deflection got the highest hardness of 73.2 HRB resulting in smaller steel grains. At a deflection of 6mm it can be seen that the largest average grain size at the bottom is 0.635 mm2, at a deflection of 12 mm the largest grain size value is located at the bottom of 0.0449 mm2, and at a deflection of 18 mm the largest grain size is at the bottom. 0.0378 mm2. then the smallest hardness of 40.9 HRB causes the steel grains to get bigger. In the wear test, the harder the object being tested, the stronger the wear resistance.Keywords: Secondary Spring, CVT, Performance, Dyno Test, Honda Scoopy.

Keyword : *deflection, Deformation, Bending*

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1. Introduction

Bending Process OverviewThe bending process is a metal-forming technique where metal is shaped using a bending machine to achieve a desired curvature. To create a product through bending, an external force (deflection) is required. Generally, the advantage of the bending process is its cost-effectiveness for small to medium production volumes. However, its disadvantages include the occurrence of springback; when the pressure on the metal is released at the end of the process, stored elastic energy in the bent section causes the material to partially return to its original shape .[1]

Types of Bending MachinesBending processes utilize various types of machines, which generally consist of:Manual Bending Machines: Machines that still rely on human power to perform the bend.Hydraulic Bending Machines: Machines driven by a hydraulic system as the primary source of power and bending force.Mechanical Bending Machines: Machines that utilize an electric motor equipped with a gearbox to allow for adjustable bending speeds. .[2]

Research Context This study utilizes a mechanical bending process on hollow profile steel with dimensions of 3 mm x 3 mm and a thickness of 1 mm. Consequently, this research focuses on the field of materials engineering, titled: "The Influence of Lateral Deflection Variations on Hollow Profile Steel Toward Wear Resistance, Hardness, and Microstructure Resulting from the Bending Process.

1.1. The research problems addressed in this study area.

a) A How does the mechanical bending process, with deflection variations of 6 mm, 12 mm, and 18 mm, affect the microstructure of 3 mm x 3 mm hollow profile steel (1 mm thickness) compared to its initial state?
b) How does the mechanical bending process, with deflection variations of 6 mm, 12 mm, and 18 mm, affect the wear resistance of 3 mm x 3 mm hollow profile steel (1 mm thickness) before and after bending?
c) How does the mechanical bending process, with deflection variations of 6 mm, 12 mm, and 18 mm, affect the hardness properties of 3 mm x 3 mm hollow profile steel (1 mm thickness) before and after bending?

1.2 Research LimitationsThe limitations of this research are as follows:

a. The material used is 3 mm x 3 mm square hollow profile steel with a thickness of 1 mm.
b. The bending equipment utilized is a mechanical bending machine.
c. The deflection variations are set at 6 mm, 12 mm, and 18 mm.
d. The testing scope includes:
   1) Microstructure observation,
   2) Hardness testing, and
   3) Wear resistance testing.

1.3 Objectives of this study are:

a. To determine the grain size resulting from microstructure observations after the bending process using deflection variations of 6 mm, 12 mm, and 18 mm.
b. To determine the hardness values obtained from testing the specimens after bending with deflection variations of 6 mm, 12 mm, and 18 mm.
c. To determine the wear rate/values resulting from wear testing after bending with deflection variations of 6 mm, 12 mm, and 18 mm.

1.4 Research BenefitsThe benefits of this research are:

a. For the researcher, to identify grain size and analyze microstructure test results on square hollow profile steel specimens at deflections of 6 mm, 12 mm, and 18 mm.
b. For future researchers, to further develop hardness test results by adjusting deflection levels to identify the hardness limits of square hollow profile steel.
c. For future studies, to continue the research by analyzing the stress and strain levels occurring in square hollow profile steel after bending at deflections of 6 mm, 12 mm, and 18 mm.

1.5 Mechanical Bending Machine

A mechanical bending machine is a type of bending equipment where an electric motor serves as the primary drive system. However, this machine does not rely solely on the motor for its operation, as it also incorporates manual human power.

Figure 1. Mechanical Bending Machine. Source

1.6 Deflection

It is a process of shape deformation in a material from one dimension due to a load applied to that material.

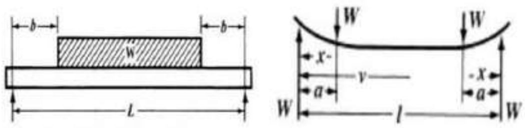


Figure 2. Deflection

There are two types of deflection, namely:

- Axial Deflection Axial deflection is deflection caused by a load acting parallel to the cross-section.
- Lateral Deflection Lateral deflection is deflection that occurs when the load acts perpendicular to the axis of the bar.

1.7 Deformation

Deformation is a change in the shape of a material caused by applied force or temperature changes. Deformation can be categorized into two types: plastic deformation and elastic deformation .[3]

- Elastic Deformation
  Elastic deformation is a change in shape that occurs when a load is applied to an object, and the deformation disappears when the applied force is removed, or the object returns to its original state (Syaukani et al. 2021).
- Plastic Deformation
  Plastic deformation is a permanent change in shape, even after the applied force has been removed .[3]

1.8 Dislocation

A dislocation is a displacement or movement of atoms within a metal due to mechanical stress created by plastic deformation (permanent change in shape).

During cold working, the number of dislocations within the metal increases, which enhances the metal's strength while decreasing its ductility. There are several types of dislocations:

1. Edge Dislocation
   An edge dislocation occurs where there is an extra half-plane of atoms within the crystal structure, and its edge terminates in the middle of the lattice.
2. Screw Dislocation
   A screw dislocation occurs due to shear stress, where the upper part of the lattice is shifted by one atomic distance relative to the lower part, creating a spiral path.
3. Mixed Dislocation
   A mixed dislocation is a dislocation in a material that exhibits components of both types mentioned above. In many materials, dislocations are found where the direction line is neither purely perpendicular nor purely parallel

1.9 Stress and Strain

1. StressStress is a system of external forces or loads acting on an object, which is resisted by the internal forces of the object. Stress is typically denoted by the symbol sigma (σ).[4]
2. StrainStrain occurs when a force or load acts on an object, causing it to undergo deformation. This deformation per unit of length is known as strain. Strain is typically denoted by the symbol epsilon (ε).[4]

2. Methodology of Research

2.1 Research Flowchart

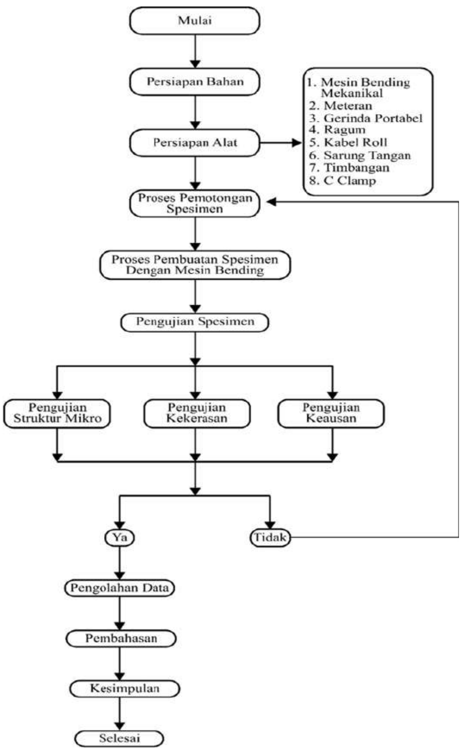


Figure 3. Research Flowchart

2. 2 Research Design

2.2.1 Research Equipment

A mechanical bending machine is a type of bending machine that uses an electric motor as its primary driver. However, mechanical bending machines are not only operated by motors; they also utilize human power for their operation.

Figure 4. Mechanical Bending Machine

2.2.2 Research Materials

1. Square Profile Hollow Steel
   Square profile hollow steel is the specimen used for the bending process, with dimensions of 30mm x 30mm and a thickness of 1mm. The experiment utilizes deflection variables of 6, 12, and 18 mm.

Figure 5. Hollow Structural Section

3. Result and Discussion

3.1 Research Result Data

3.1.1 Composition Test Result Data of Square Profile Hollow Steel

Table 1. Composition Test Result Data of Square Profile Hollow Steel

Chemical Element	C	Mn	P	S	Si	Sn
Chemical Composition	0,0809	0,5319	0,0141	0,0111	0,0162	0,0019
Chemical Element	Al	Cr	Cu	Ni	Nb	V
Chemica Composition	0,062	0,0245	0,0518	0,0095	0,0039	0,0004
Chemical Element	Ca	Mo	Co	B	N	Ti
Chemica Composition	0	0,0092	0,0044	0,0001	0,076	0,0004

3.1.2 Bending Test Result Data

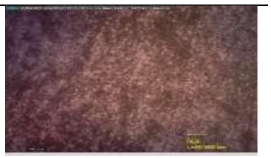
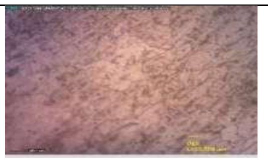
Table 2. Bending Test Result Data

Kode	Defleksi	L1	L2	BA	BS	BB
6BA	6mm		898	30,35	28,13	30,29
12BS	12mm	900 mm	895	30,88	27,46	30,28
18BB	18mm		890	30,9	27,15	29,79

Note
L1 = Initial Length
L2 = Final Length
6 = Deflection (mm)
BA = Top Section
BS = Side Section
BB = Bottom Section

3.1.3 Microstructure Test Result Data of Square Profile Hollow Steel

Table 3.3. Microstructure Test Result Data of Hollow Steel

Material Type	Specimen Code	Microstructure Test Results
Square Hollow Section (SHS) Steel	Li	
	6BA	
	6BS	
	6BB	
	12BA	
	12BS	
	12BB	
	18BA	
	18BS	
	18BB	

Note
6 = Deflectioni (mm)
BA = Top Section
BS = Side Section
BB = Bottom Section

3.1.4 Hardness Test Result Data of Square Profile Hollow Steel

Table 3.4. Hardness Test Result Data of Square Profile Hollow Steel

HARDNESS TEST							
Material Type	Specimen Code	Hardness (HRB)					Average Hardness
Baja Hollow	Li	68	67,5	61	68	60	64,9
	6BA	54	56	51	59	54,5	54,9
	6BS	55,5	51,5	57	61	49,5	54,9
	6BB	58	58	53	53,5	52	4,9
	12BA	66,5	65,5	70,5	57	64	64,7
	12BS	51,5	63,5	64,5	49	50	55,7
	12BB	52	42	46,5	51	45	47,3
	18BA	71	70,5	77	72,5	75	73,2
	18BS	79	71	63	63	62	67,6
	18BB	35	45	41,5	36	47	40,9

Note
6 = Deflectioni (mm)
BA = Top Section
BS = Side Section
BB = Bottom Section

3.1.5 Hardness Test Result Data of Square Profile Hollow Steel

Table 3.5. Wear Test Result Data of Square Profile Hollow Steel

Specimen Code	Load	Time (minutes)	Weight			Linear Speed (m/min)	Sliding Distance (m)	Wear Rate (g/m)
			awal	akhir	hilang			
L1	10	0,5	6,15	6,14	0,01	78,5	39,25	0,00025477
6BA	10	0,5	7,11	7,07	0,04	78,5	39,25	0,001019108
6BS	10	0,5	6,79	6,75	0,04	78,5	39,25	0,001019108
6BB	10	0,5	7,02	6,97	0,05	78,5	39,25	0,001273885
12BA	10	0,5	5,6	5,57	0,03	78,5	39,25	0,000764331
12BS	10	0,5	5,32	5,28	0,04	78,5	39,25	0,001019108
12BB	10	0,5	5,92	5,87	0,05	78,5	39,25	0,001273885
18BA	10	0,5	5,67	5,66	0,01	78,5	39,25	0,000254777
18BS	10	0,5	5,45	5,42	0,03	78,5	39,25	0,000764331
18BB	10	0,5	5,66	5,6	0,06	78,5	39,25	0,001528662

Note

6 = Deflectioni (mm)

BA = Top Section

BS = Side Section

BB = Bottom Section

3.1.6 Grain Size Calculation Data of Square Profile Hollow Steel

Table 3.6. Grain Size Calculation Data of Square Profile Hollow Steel

Grain					
SPECIMENT CODE	N1	N2	Na	G	Average Diameter Grain
6BA	85	46	864	6,799226	0,0378
6BS	27	20	296	5,254688	0,0635
6BB	18	30	264	5,089725	0,0635
12BA	70	45	740	6,575849	0,0378
12BS	25	21	284	5,195017	0,0635
12BB	59	39	628	6,339226	0,0449
18BA	68	47	732	6,560177	0,0378
18BB	74	35	732	6,560177	0,0378
18BS	16	36	272	5,132769	0,0635

Note

6 = Deflectioni (mm)

BA = Top Section

BS = Side Section

BB = Bottom Section

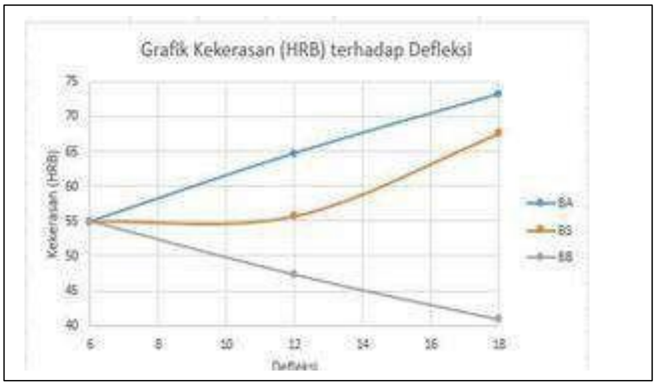
N1 = Number of grains within the circle

N2 = Number of intercepted grains

Na = Number of grains

The chemical composition analysis of the square profile hollow steel shows that the primary elements are 0.0809% C and 0.5319% Mn (Table 4.1). Based on these results, the material is classified as low-carbon steel, which is characterized by high ductility and excellent formability. According to the Fe-Fe3C equilibrium diagram, low-carbon steel with 0.0809% C is a hypoeutectoid steel < 0,83% C consisting of a ferrite (α) phase, which is ductile, and a pearlite (α+Fe3C) phase, which has lower toughness.The (α) phase has a maximum carbon solubility of 0.025% C at a temperature of 723 ^{O}C with a Body-Centered Cubic (BCC) crystal structure; at room temperature, it has a carbon solubility limit of 0.008% C. The characteristics of ferrite include:a) low toughness,b) relatively high ductility,c) a hardness value of less than 90 HRB, andd) corrosion-resistant properties.The 0.5319% Mn content is below 3%, thus it does not significantly influence the hardness of the (α) phase. However, this manganese content assists in the deoxidation of the steel, prevents the formation of Fe-S inclusions, and improves machinability. Other elements such as 0.01411% P, 0.0111% S, 0.0019% Sn, 0.0062% Al, 0.0518% Cu, 0.0095% Ni, 0.0039% Nb, 0.0004% V, 0% Ca, 0.0092% Mo, 0.0044% Co, 0.00001% B, 0.0076% N, and 0.0004% Ti (Table 4.1) are considered impurities or trace elements.Furthermore, the bending test data (Table 4.2)

indicates that the value of L2 (final length) decreases as the applied deflection increases. The top surface (BA), side surfaces (BS), and bottom surface (BB) undergo changes due to the pressure applied by the upper roll. The dimensional changes at the top section (BA) show an increase in size because direct contact with the roll causes the specimen to expand. Conversely, the dimensions of the side sections (BS) decrease; since the sides are in a vertical position, they undergo a reduction in dimension under load. The bottom section (BB) dimensions also decrease because the specimen is pulled toward Roll 1 and Roll 2 located at the base during the rolling process.



Graph 4.1. Graph of Hardness Values for Square Profile Hollow Steel against Deflection Variations

Analysis of Hardness, Microstructure, and Wear Results. The hardness test results for the square profile hollow steel after the bending process reveal three key findings:

- Top Section (BA): It is evident that increased bending results in higher hardness (Graph 4.1), which is further supported by the microstructure analysis in Table 4.3.

- Side Section (BS): Similarly, increased pressure during bending leads to higher hardness (Graph 4.1), following the same trend as the top section.
- Bottom Section (BB): In contrast, hardness decreases in this area (Graph 4.1). This occurs because the surface is further from the roll contact point. Microstructural analysis shows that the grains in the bottom section (BB) become larger or more elongated.

Based on the hardness data, the top section (BA) exhibits higher hardness compared to the bottom section (BB), where the values progressively decline. For the deflection variations of 6 mm, 12 mm, and 18 mm, the hardness values consistently increase in the top (BA) and side (BS) sections. This indicates that both the deflection level and the specific section of the profile significantly influence hardness. Specifically, higher deflection in the BA and BS sections leads to grain refinement (smaller grains), while the BB section experiences grain growth or grain stretching (Table 4.3).

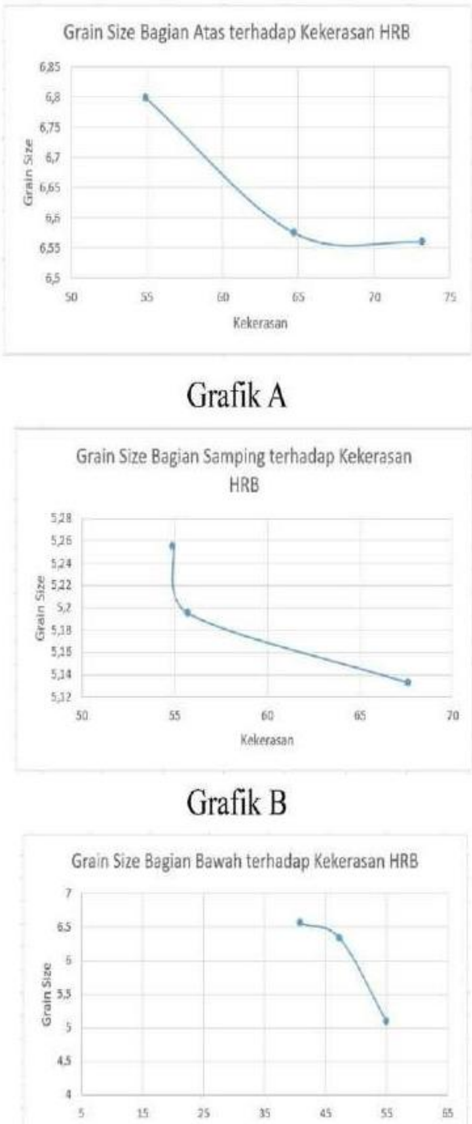
Observation of specimens 6BA, 12BA, and 18BA shows an increase in hardness (Graph 4.1) driven by the reduction in grain size (Table 4.3). Specimens 6BS, 12BS, and 18BS also show a similar increase in hardness as the grains shrink or undergo compression due to the pressure exerted by the upper roll of the bending machine. Conversely, in the 6BB, 12BB, and 18BB specimens—the areas furthest from the roll—the grains appear larger or more spaced out because the material in the bottom section of the specimen undergoes stretching (tension).

The wear test results for the square profile hollow steel after bending show that wear resistance increases in the top section (BA) and side section (BS). However, the bottom section (BB) shows a decrease in wear resistance (or lower wear rates) because this area experiences minimal friction or contact with other materials during the bending process (Graph 4.2).

Graph 4.2. Graph of Wear Values for Square Profile Hollow Steel against Deflection Variations

The wear rate results for the square profile hollow steel after bending show that the highest wear rate occurred at 18 mm deflection in the bottom section (BB), reaching 0.001529 g/s (Table 4.5); consequently, this area exhibits low wear resistance. In contrast, the lowest wear rate among the bent specimens was found at 18 mm deflection in the top section (BA), reaching 0.000255 g/s (Table 4.5), which indicates high wear resistance. The base metal (original material) of the hollow steel showed the overall lowest wear rate of 0.000255 g/s (Table 4.5), demonstrating superior wear resistance compared to the specimens subjected to 6 mm, 12 mm, and 18 mm deflections.

Regarding the Grain Size calculations, it can be observed that as the grain size decreases, the hardness value increases. As shown in the lower section of the chart (Graph 4.3), at 6 mm deflection in the bottom section (BB), the hardness is significant, and the grain size is notably refined (Graph 4.3). This phenomenon aligns with the Frank-Read mechanism and established metallurgical theories stating that a smaller grain diameter in a metal leads to greater strength. Since strength is directly proportional to hardness, an increase in the metal's strength subsequently results in higher hardness values.



Graph 4.3 Relationships Between Grain Size and Hardness. a) (BA) Grain Size vs. Hardness, b) (BS) Grain Size vs. Hardness. c). (BB) Grain Size vs. Hardness

4. Conclusions

Based on the fabrication and testing of square profile hollow steel using a mechanical bending machine with various deflection levels, the following conclusions are drawn:

- Microstructure: The microstructural analysis of the square profile hollow steel before and after bending at deflections of 6 mm, 12 mm, and 18 mm shows that in the top section (BA), increased deflection leads to grain refinement (smaller grain size). A similar trend is observed in the side section (BS), where the grains also decrease in size. Conversely, in the bottom section (BB), the grain size increases (grain growth/stretching) due to the greater distance from the contact roll.
- Hardness: The highest hardness value was obtained at 18 mm deflection in the top section (BA), with an average hardness of 72.3 HRB. The side section (BS) also showed an increase in hardness, reaching 67.6 HRB. In contrast, the bottom section (BB) experienced a decrease in hardness due to its distance from the roll, resulting in an average hardness of 40.9 HRB.
- Wear Resistance: The wear test results for the square profile hollow steel indicate that the highest wear rate occurred at 18 mm deflection in the bottom section (BB), reaching 0.001529 g/s. The lowest wear rate was recorded in the top section (BA) at 0.000255 g/s, indicating superior wear resistance in the compressed area.

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