Tensile and flexural behaviour of steel materials used in the construction of crop processing machines

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Abstract: This experiment investigated the mechanical properties of mild steel, galvanized iron and stainless steel when subjected to tensile and flexural loading. Work pieces of 54 samples were prepared having a gage length of 30 mm for material thicknesses of 1, 1.5 and 2 mm which was replicated three times. Properties such as peak force at break, elongation at break, stress, and strain of the materials were studied using a testometric M500-100AT Universal Testing Machine (UTM). The peak force obtained for mild steel was 2495.43, 4643.33 and 6215.67 N for 1, 1.5 and 2 mm respectively. The elongations of mild steel were 48.88, 54.77 and 56.11 mm for 1, 1.5, and 2 mm respectively. For stainless steel tensile strength analysis, the peak forces obtained are 9486.66, 9558.00 and 9522.33 N for 1, 1.5 and 2 mm respectively. The deformation of the material occurred at similar loads having stresses of 535.20, 583.71 and 56.11 mm for the thicknesses investigated. Similarly, the stress-strain relationship of the material ranged from 10131.20 N/mm² to 12757.33 N/mm² while the elongation amount of strain it can withstand before failure are 30.54, 38.64 and 47.74 mm. The bending strength for mild steel both at peak and at break increased as the thickness increases. Bending strength at peak are 364.50, 378.33 and 381.87 N/mm² for 1, 1.5 and 2 mm respectively with 2 mm expectedly showing the greatest bending strength. Also, for stainless steel, the deflection of the different length of stainless steel at peak increased as the length increased unlike for mild steel with a reverse case. The deflection at break decreased as the length of the materials increases. The bending strength at peak and the bending modulus increased as the length of the material was increased, while at break the reverse was the output. From this investigation, it can be observed that stainless followed by mild steel have higher tensile and yield strength than galvanized iron. This explain the wide applications of stainless steel and mild steel in various crop processing machines constructions and other engineering uses that require high strength.

1. Introduction

Engineering materials are at the centre of production processes such as automobile manufacturing, building and infrastructure construction, power plants, aircraft, ship building and the manufacturing of farm machinery. These materials are subjected to different forces under loading which impact their optimal performance during operation. The knowledge of the behaviour of these materials when subjected to such forces is important to forestall incessant failure or collapse of a system. Steel is among the most widely used engineering materials as it applications cut across all facet of human endeavours. Properties such as
rigidity, toughness, durability etc., have earned these materials this popularity. Steel materials come in different grades such as mild, galvanized and stainless steel, which are the most used material for the construction of crop processing machinery [1]. Crop processing machines are an indispensable parts of farm infrastructure. They are used in the post-harvest treatments of harvested crop produce that help to improve the value and conditions of agricultural products. Such machines are the sheller, thresher, de-huller, decorticator and peeler [2,3,4]. These machines are subjected to different forces during operation such as tensile, flexural, compressive, impact, creep, and torsional etc., depending on their mechanism of operations. These affect the structural compositions of the construction material and most time results in machine failure under use when these forces exceeded the tolerance level of the construction materials [5, 6, 7, 8].

Material availability and their right application have been pressing scientific problems human constantly face. The mechanical characteristics of materials determine the type of engineering applications it can be used for. For safe design of structural components in farm machinery, the mechanical properties of the materials employed for construction should be established as many engineering failures are directly linked to failure of machine parts or construction materials. An in depth knowledge and understanding of the strength characteristics of machine construction materials is essential toward having an efficient and functional machine. Most often crop processing machines are constructed using locally available materials without taking into cognizance their mechanical strength and behaviour when subjected to forces such as tensile and flexural as most data in this area of knowledge are mostly related to material used in building construction. These have rendered most of these machines un-usable for their intended functions resulting in a pool of non-functional crop processing machines in most engineering workshops. It may be possible that some of these locally available construction materials may not conform to establish material standards and specifications. Hence investigation into material strength analysis as it relate to tensile and flexural characteristics is key for a viable, reliable, durable and cost effective machines for crop processing. Hence, this study investigated the tensile and flexural behaviour of steel materials used for crop processing machine construction. As design of engineering structures is based on the mechanical properties of the materials used, the mechanical strength of the materials should meet the strength requirements of the structural applications. The understanding of material composition and property relationship will therefore help to determine the effectiveness of the material in design process and application.

2. Materials and Methods

2.1 Sample Characteristics and Preparation

The stress-strain relationship of various metals can be utilized to predict the behaviour of materials when exposed to different types of loadings. Material strength indicators such as force at yield, force at break, stress at peak, strain at peak, elongation at break, Young’s modulus, deflection at peak, bending strength at peak as indices that defined mechanical properties were investigated. The materials and equipment used for the investigation were mild steel, galvanized, stainless steel, universal testing machines, digital vernier calipers, grinder, cutter and file. Three thicknesses namely 1, 1.5, 2 mm of the steel materials were used for the work piece preparation based on their level of usage in crop processing construction.

Steel materials were sourced locally from Omu-Aran, Kwara State, Nigeria. These were cut into sizes taking into account the gage length of the work piece (Figure 1). The work piece dimensions were 70 mm length having a gage length of 30 mm and 20 mm width. The gage length between the fixed lower and upper base was estimated to decide the underlying length of the sample experiencing the uniaxial pressures.
The work pieces were prepared using vernier caliper, hammer, chisel, grinder, cutter and file. For both the tensile and flexural tests, 54 work pieces were prepared which was subjected to uniaxial and compressive loading respectively using the universal testing machine.

2.2 Experimental Procedures

The materials testing machine used was a testometric M500-100AT range of twin column, computer controlled universal materials testing machine. It is a machine capacity of 100 kN, speed range of 0.001 to 500 mm/min in steps of 0.001 mm/min, crosshead travel (excluding grips) of 1059 mm, and throat of 420 mm (Figure 2). Using digital vernier caliper, the thickness, width and gage length of each work piece were obtained. The work piece was fixed to the jaw of the UTM and adjusted to fit the dimensions of the specimens for maximum grip (Figure 3). Measured dimensions were input into the material testing machine and operated until the materials failed. The data measured were automatically logged by the system on a spreadsheet. Some of the indicators measured were the force at peak, force at yield, force at break, elongation at break, stress at yield, strain at yield, Young modulus, etc. These were used to analyze the mechanical characteristics of the investigated materials.

The testing machine was designed to determine the stress-strain curves of the materials investigated. Tensile and elongation testing are major material test in which a specimen is exposed to uniaxial tension or compression until the material fails. The test can give much vital data about the material of the sample, such as, the measure of energy required to break a material, modulus of material, the purpose of perpetual twisting, stress-strain, bends, and tear etc. This data can be utilized to display a better comprehension of known materials. A typical bit of hardware utilized for ductile testing is the widespread testing machine, which tests materials in strain, pressure, or bowing [9]. The Young’s modulus is of critical importance in the engineering applications of materials/metals that are subjected to deflections [10].

![Standard Sample Model Showing the Gage Length and Thickness of a Work Piece](image.png)
2.3 Some useful Relationships in Mechanical Properties Investigations

2.3.1 Tensile Test

Tensile test of a material represents one of the most essential tests to decide stress–strain characteristics [11]. A straightforward uniaxial test comprises of gradually pulling a specimen of a material with tension until it breaks. Tensile tests were carried out for a number of reasons with the main being for engineering applications. This kind of test causes material to undergo deformations such as either elastic or plastic. The elastic type shows a linear relationship between the extension and the applied load. Engineering stress $\sigma$ is expressed by the ratio of load applied to the original cross sectional area, while engineering strain $\varepsilon$ is given by the change in length (extension) $\Delta L$ over the original length $L$, Equation 1 and 2 [12].

$$\sigma = \frac{P}{A_o}$$

(1)

$$\varepsilon = \frac{\Delta L}{L_o}$$

(2)

where,

- $\sigma$ - engineering stress; $P$ - applied axial load; $A_o$ - original cross sectional area; $\varepsilon$ - engineering strain; $\Delta L$ - extension; $L_o$ - original length

The engineering stress-strain behaviour for elastic deformation is based on Hooke’s law. The gradient on this curve depicts a modulus of elasticity called the Young’s Modulus, $E$ as expressed in Equation 3.

$$E = \frac{\sigma}{\varepsilon}$$

(3)

where

- $E$ - Young’s modulus; $\sigma$ - engineering stress; $\varepsilon$ is the engineering strain

The maximum tensile strength can be read off a stress-strain graph as the highest stress value. Alternatively, maximum tensile strength can be estimated by dividing the maximum applied load by the cross sectional area, Equation 4.

$$\text{Maximum tensile strength} = \frac{\text{Maximum load}}{\text{Cross sectional area (CSA)}} = \frac{\text{Stress x CSA}}{\text{CSA}}$$

(4)
2.3.2 Flexural Strength Test
Flexural strength also known as modulus of break or crack quality estimates the rigidity and ability of alloys to oppose load in bending, an estimation of the load bearing capacity of a material [13]. Test samples of three thicknesses with dimensions (1, 1.5 and 2) x 30 x 150 mm were measured. The quality was tried under two points stacking according to I.S.516-1959. The 1, 1.5 and 2 mm of successful range partitioned into three equivalent lengths. Those were laid on a testing machine for flexural strength. While testing was done the heap was expanded step by step and the failure point load was noted at which the specimen was deformed. Equation (5) is an expression for the flexural strength in MPa.

\[
F.S. = \frac{P \times L}{b \times d^2}
\]

where,
F.S- Flexural strength (Mpa); P = Failure Load (N); L = Distance between the backings from focus to focus (mm); b = Samples width (mm); d = Specimen thickness (mm)

The flexural strengths of the samples were measured at a cross-head speed of 10 mm/min using a universal testing machine. Each data point represents an average of three observations. Three point flexural tests were carried out for each sample. From the flexural strength test, the Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) can be calculated. Samples of 150 mm long, 30 mm wide and 1, 1.5 and 2 mm thickness prepared was used. The Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) were calculated from load deflection curves given by the testing machine according to the following expression (Equation 6 and 7).

\[
MOR = \frac{3PL^3}{4bh^2}
\]

\[
MOE = \frac{PL^3}{4bh^3Y}
\]

where,
P= Maximum load or maximum force; L= Span; h=Thickness; b= Width; Y= Deflection.

3. Results and Discussion

3.1 Tensile Test Evaluation of Mild-Steel

Table 1 shows the peak force at break, elongation at break, stress, and strain of mild steel samples when subjected to varying tensile tests. The peak force obtained for mild steel are 2495.43, 2495.43 and 6215.67 N for 1, 1.5 and 2 mm respectively. Accordingly, materials thickness influences tensile deformation implying thicker material can resist force to a great extent than the thinner one. This may be due to the bond existing among the closely packed particles of the materials. The 2 mm thick material can resist force to a 6215.67 N having a young modulus ranging from 185.43 - 187.37 N before elongation takes place. Hence, mild steel material with bigger thickness will need higher force for it to deform or elongate. The elongations of the mild steel were 48.88, 54.77 and 56.11 mm for 1, 1.5 and 2 mm respectively. The elongation represents the deformation, a measure of the ductility of a material, implying the amount of strain it can withstand before failure in tensile testing [10]. The elongation values of mild steel which are relatively large may be due to the presence of substitution atoms which impede the movement of dislocations.

| Thickness (mm) | Peak for at break (N) | Elongation at break (mm) | Stress (N/mm²) | Strain | Young’s (N/mm²) | Young’s modulus |
|---------------|------------------------|--------------------------|----------------|--------|-----------------|-----------------|
| 1             | 2495.43                | 48.88                    | 1663.63        | 8.88   | 187.37          |                 |
| 1.5           | 4643.33                | 54.77                    | 2059.26        | 16.11  | 127.81          |                 |
| 2             | 6215.6                 | 56.11                    | 2738.56        | 14.77  | 185.43          |                 |
3.2 Tensile Test Evaluation of Stainless-Steel

Table 2 depicts varying tensile tests for stainless-steel samples when subjected to tensile loading. These establish the peak force at break, elongation at break, stress, and strain of the material. The peak force obtained for mild steel are 9486.66, 9558.00 and 9522.33 N for 1.5 mm and 2 mm respectively. The deformation of the material occurred at similar loads with a stress of 583.506 and 486.875 N/mm². It is however, imperative to note at a lesser thickness (1.5 mm) the material displayed better tensile strength. The stress-strain relationship of the material ranged between 1031.20 N/mm² to 12757.33 N/mm² while the elongation, amount of strain it can withstand before failure varied between 30.54 mm and 47.74 mm. It is observed that stainless steel tends to reduce in tensile strength if it is not treated unlike mild steel. Mild steel yield strength is typically 65-70% of the tensile strength.

Table 2. Tensile Strength of Stainless Steel

| Thickness (mm) | Peak force at break (N) | Elongation at break (mm) | Stress (N/mm²) | Strain | Young’s modulus (N/mm²) |
|----------------|-------------------------|--------------------------|----------------|--------|------------------------|
| 1              | 9486.66                 | 9.46                     | 535.20         | 30.54  | 10131.20               |
| 1.5            | 9558.00                 | 11.59                    | 583.51         | 38.64  | 11294.30               |
| 2              | 9522.33                 | 14.32                    | 486.88         | 47.74  | 12757.33               |

3.3 Tensile Test Evaluation of Galvanized Iron

Table 3 display varying tensile tests for galvanized iron samples when subjected to tensile loading to depict the peak force at break point, elongation at break point, stress, and strain of the material. The peak force at break obtained for galvanized iron was 775.00, 4066.60 and 4745.20 N for 1, 1.5 and 2 mm respectively. The elongation at break ranges from 45.25 to 45.90 mm with 1 mm thick material having the highest while 1.5 mm has the least. In term of strain and Young’s modulus, 1 mm exhibited better value but less in term of stress.

Table 3. Tensile Strength of Galvanized Steel

| Thickness (mm) | Peak force at break (N) | Elongation at break (mm) | Stress (N/mm²) | Strain | Young’s modulus (N/mm²) |
|----------------|-------------------------|--------------------------|----------------|--------|------------------------|
| 1              | 775.00                  | 45.90                    | 75.00          | 19.67  | 21215.05               |
| 1.5            | 4066.60                 | 42.25                    | 175.40         | 10.40  | 20295.85               |
| 2              | 4745.20                 | 42.78                    | 275.79         | 9.27   | 19376.65               |

3.4 Bending Test Evaluation of Mild Steel

Table 4 shows flexural test of mild steel which depicts the strength of the material or its resistance to bending (compressive) load. Materials used as screen in crop processing machines are subjected to this kind of force. Different types of material and the size of materials respond differently to bending forces and even materials of the same type, but different sizes respond differently to bending forces. In this instance flexural test was done on mild steel of thickness 1, 1.5 and 2 mm. Length of material influences bending force as the more the length of the material the more force would be required to break the material and the lesser the deflection it would undergo at peak, the results were vice versa for deflection done at break. The bending strength both at peak and at break increases as the thickness increases. Bending the strength at peak are 364.50, 378.33 and 381.87 N/mm² for 1, 1.5 and 2 mm respectively with 2 mm expectedly showing the greater bending strength.
### Table 4. Flexural Test Results for Mild Steel

| Sample Thickness (mm) | Force at break (N) | Deflection at peak (mm) | Deflection at Break (mm) | Bending strength at peak (N/mm²) | Bending strength at Break (N/mm²) | Bending Modulus (N/mm²) |
|-----------------------|--------------------|-------------------------|--------------------------|---------------------------------|----------------------------------|------------------------|
| 1                     | 48.60              | 22.06                   | 28.12                    | 364.50                          | 302.00                           | 79428.27               |
| 1.5                   | 113.23             | 22.00                   | 26.25                    | 378.33                          | 327.83                           | 95228.18               |
| 2                     | 165.1              | 18.08                   | 23.21                    | 381.87                          | 363.0                            | 105890.99              |

3.5 Bending Test Evaluation of Stainless Steel

The flexural test result for stainless steel is as shown in Table 5. The results obtained were similar compared to those of mild steel and the deflection of the different length of stainless steel at peak increased as the length increased unlike for mild steel which was the reverse. The deflection at break decreased as the length of the material was increased. The bending strength at peak and the bending modulus increased as the length of the material was increased, while at break the reverse was the results. For stainless steel the results have a smaller difference compared to those of mild steel.

### Table 5. Flexural Test results for stainless steel

| Sample Thickness (mm) | Force at break (N) | Deflection at peak (mm) | Deflection at Break (mm) | Bending strength at peak (N/mm²) | Bending strength at Break (N/mm²) | Bending Modulus (N/mm²) |
|-----------------------|--------------------|-------------------------|--------------------------|---------------------------------|----------------------------------|------------------------|
| 1                     | 90.80              | 20.49                   | 51.43                    | 201.78                          | 144.44                           | 31197.57               |
| 1.5                   | 96.95              | 22.03                   | 46.23                    | 215.44                          | 140.56                           | 32428.91               |
| 2                     | 103.10             | 23.58                   | 48.43                    | 229.11                          | 136.67                           | 33660.26               |

3.6 Bending Test Evaluation of Galvanized iron

The values of the force needed at break for the materials respectively were increasing slowly as compared to the other two (Table 6). As the length was increased so was the force increasing, while the deflection at peak, bending strength at peak and bending strength at break was increasing as the length was been increased at peak. The bending modulus was decreasing as the thickness was increasing.

### Table 6. Flexural Test Results for Galvanized Iron

| Sample Thickness (mm) | Force at break (N) | Deflection at peak (mm) | Deflection at Break (mm) | Bending strength at peak (N/mm²) | Bending strength at Break (N/mm²) | Bending Modulus (N/mm²) |
|-----------------------|--------------------|-------------------------|--------------------------|---------------------------------|----------------------------------|------------------------|
| 1                     | 55.6               | 16.481                  | 44.552                   | 123.556                         | 89.111                           | 21707.79               |
| 1.5                   | 59.3               | 15.126                  | 44.662                   | 131.778                         | 94.222                           | 17089.414              |
The results in comparison for all the materials tested are shown in the Table 7. This depicts the mechanical properties for tensile and flexural strength, young’s modulus and the bending characteristics. Young's modulus estimates the resistance of a material to elastic deformation under load. A stiff material has a high Young's modulus and changes its shape only slightly under elastic loads. Hence, they require a high loads to elastically deform it. The Young's modulus is very important in engineering design, as this constant can explain when a structural implant will deform. This will let the design engineer to know how to design machinery.

Table 7. Summary Performance of the various Test Materials

|            | Tensile Strength |            | Flexural Strength |
|------------|------------------|------------|------------------|
|            | Galvanized       | Stainless  | Mild             | Galvanized       | Stainless  | Mild             |
| 1          | 21215.05         | 9831.27    | 187.37           | 21707.79         | 31197.57   | 79428.27         |
| 1.5        | 20295.85         | 11294.30   | 127.81           | 17089.41         | 32428.91   | 95228.18         |
| 2          | 19376.65         | 12757.33   | 185.43           | 16445.41         | 33660.26   | 105891.00        |

4. Conclusion

Failure of any crop processing machinery is an expensive endeavours which may results in the loss of investment, production down time, injury to operator and contamination of produce and the environment. Using the right material for construction will help in machines functionality and service life prolongment. The results obtained from the tensile and flexural characteristics revealed that the thicker the material the more the amount of force required before breaking, and the lesser the thickness the lesser the amount of force required to break. While for tension and elongation, the thicker the material the more the elongation/extension. As the test was done from the thin to the thick work pieces the stress and the strain ascended too, while Young’s modulus was the reverse. The data obtained from the universal testing machine revealed the difference in the rates of extensions in mild steel, stainless steel and galvanized iron.

The obtained results show that the more the thickness the more the tensile strength and flexural strength. Mild steel has exhibited the result of being suitable with high tensile and flexural strength at room temperature. However, treated stainless steel with high carbon contain has higher for both tensile and flexural strength. Mild steel may not suitable for food processing machine however it can be coated or replaced by the use of galvanized.

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