



Research article

Stress and Stiffness Analysis of Geometric Design of Structure Universal Testing Machine 1 Ton Capacity With Ribbing Technology Using Finite Element Method

Reski Septiana^{1a}, Yudha Adi Prasetyo^{2b}, Hendra^{a*}, Zuliantoni^{3b}, Hamdan Akbar Notonegoro^{4a}, Rispani^{5c}, Hernadewita^{6d}, Hermiyetti^{7e}, Fajri A. Rayhan^{8f}, M. Irfan Dzaky^{9g}, Ayu Soraya^{10h}

^aJurusan Teknik Mesin Universitas Sultan Ageng Tirtayasa, Jl. Jendral Sudirman KM 3 Cilegon Banten, 42435, Indonesia

^bProgram Studi Teknik Mesin Universitas Bengkulu, Jl W.R. Supratman Kandang Limun, Bengkulu, 38371, Indonesia

^cDepartemen Teknik Mesin, Fakultas Teknik, Universitas Andalas, Kampus Limau Manis, Padang, 25175, Indonesia

^dMagister Teknik Industri Universitas Mercubuana, Jl Meruya Selatan, Jakarta, 10650, Indonesia

^eFakultas Ekonomi Universitas Bakrie, Jl. H.R. Rasuna Said Kuningan, Jakarta, 12920, Indonesia

^fTeknik Perkapalan, Universitas Pembangunan Nasional Veteran Jakarta

^gProgram Studi D3 Pemeliharaan Alat Berat, Jurusan Teknik Mesin, Politeknik Negeri Sriwijaya

^hProgram Studi D4 Manajemen Informatika, Jurusan Manajemen Informatika, Politeknik Negeri Sriwijaya

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CORRESPONDENCE

E-mail:

hendra@untirta.ac.id

A B S T R A C T

A machine structure is designed with a high stiffness concept [1]. Low stiffness leads to deformation of the machine structure, which can degrade the quality of the resulting product. High machine structural stiffness is used in machine tools, material testing machines, and other testing machines, such as universal testing machines. High machine structural stiffness is always accompanied by a large machine design volume, which requires the use of large amounts of material, resulting in high volume and weight and high production costs. To overcome this, ribbing technology is used [2-5]. Ribbing technology functions to prevent deformation in the machine structure while reducing the machine's volume. This study aims to apply and analyze the structural stiffness of a universal testing machine with various ribbing configurations using the finite element method [6-9]. The results show that the thicker the ribbing dimension, the smaller the resulting deflection, and the smaller the deflection, the greater the stiffness. The simulation results show that the highest deflection value was obtained for the 4 mm thick Box model using AISI 1010 material (1.55 mm), while the smallest was for the 16 mm thick X model using AISI 1045 material (1.26 mm). The lowest stiffness value was found for the 4 mm-thick Box model using AISI 1010 material (6472.49 N/mm), while the highest was found for the 16 mm-thick X model using AISI 1045 material (7936.51 N/mm).

1. INTRODUCTION

The structure of a machine is designed with a high-rigidity concept, capable of withstanding loads from the work process and the components that support it [1]. The machine structure consists of columns, beds, and supporting facilities. Low rigidity results in deformation of the machine structure, thereby reducing the quality of the resulting product.

The machine structure is an important part that withstands the load or supports all loads. A tensile testing machine, or more commonly a universal testing machine (UTM), is used to conduct tensile/compressive tests. Universal testing machines (UTMs) must be rigid to support the specimen and maintain test repeatability, ensuring more accurate results. The rigidity of a universal testing machine (UTM) can be designed using the ribbing concept, with shape and dimensions specified. To determine the structural stiffness of the UTM machine as a function of variations in rib shape and dimensions, a finite element analysis was conducted [2-9].

In this study, a geometric simulation approach was used to simulate the shape and dimensions of the ribbing on the universal testing machine structure using the finite element method. The finite element method (FEM) analysis yielded deflection values from variations in the ribbing shape and dimensions of the machine components. The high rigidity of the machine structure is accompanied by a large machine design volume, which requires the use of many materials and results in high production costs. To reduce the large volume and maintain the machine's rigidity, ribbing technology is used to prevent deformation while reducing the machine's overall volume.

2. MATERIALS AND METHODS

2.1 Stage of Research

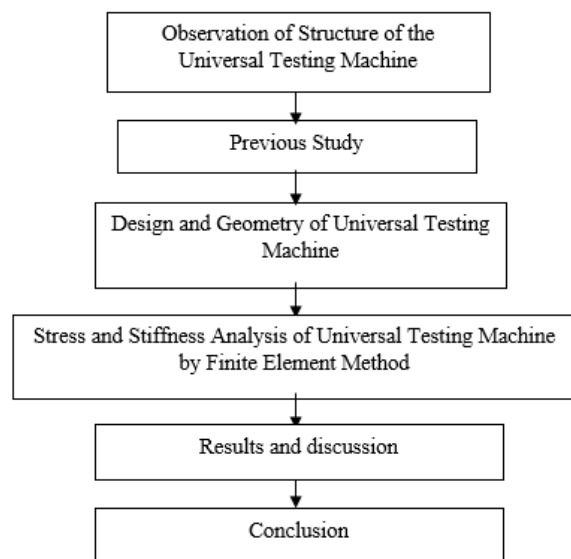


Figure 1. Stage process of research.

Figure 1 shows the research stage in a previous study of the UT's observation structure. Then, design and geometry of UTM using a 3D model, and applying ribbing technology to structural, stress, and stiffness analysis by the finite element method (FEM): results and conclusion.

2.2 Stiffness, Stress, and Strain

Stiffness

Stiffness in machine structures is crucial because it prevents deformation beyond the allowable limit. Stiffness is the resistance to deformation under loading. The stiffness value is derived from the relationship between load (F) and deformation (δ) [1].

$$k = \frac{F}{\delta} \quad (2.1)$$

Where :

$$\begin{aligned} k &= \text{Stiffness} \\ F &= \text{Force (N)} \\ \delta &= \text{Deflection (mm)} \end{aligned}$$

Stress and Strain

The values of stress, strain, and deformation that occur in a structural analysis must be taken into account. Stress is the force per unit area, as shown in equation (2.2) [2].

$$\sigma = \frac{F}{A} \quad (2.2)$$

Where:

$$\begin{aligned}\sigma &= \text{Stress (N/m}^2\text{)} \\ A &= \text{Area (m}^2\text{)}\end{aligned}$$

Strain is the ratio of the increase in length to the initial length of a structure. Strain can also be seen in equation (2.3)[2].

$$\epsilon = \frac{\delta}{L} \quad (2.3)$$

Where :

$$\begin{aligned}\epsilon &= \text{Strain} \\ \delta &= \text{Deflection (mm)} \\ L &= \text{Length (m)}\end{aligned}$$

The linear relationship between stress and strain for a bar under tension or compression is described by Hooke's Law (2.4) [2].

$$\sigma = E\epsilon \quad (2.4)$$

Where:

$$E = \text{Young Modulus (Pa)}$$

2.3 Ribbing, UTM Structure, and FEM Simulation

The machine structure functions as a support for the machine's supporting components. The machine's structural components must be highly rigid, including the bed, column, and other supporting components. A well-designed structure can withstand deformation from static and dynamic loads during operation, ensuring accurate measurement results [1].

Ribbing is a technology used to stiffen a machine structure to prevent excessive deformation and maintain low volume [1-5]. Ribbing is commonly used in machine tools, such as lathes. In lathes, ribbing is used on the bed, as seen in Figure 2[1].

The finite element method (FEM) is used to analyze the stress, deformation, and stiffness of machine tool structures, machine components, and related systems. FEM can also be used to calculate stress, thermal stress, and fatigue in the design phase of a machine, and to design a product to predict stress and deformation. [11-16]

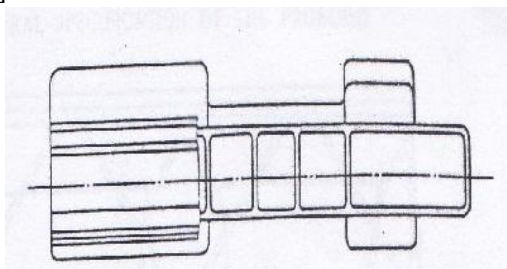


Figure 2. Ribbing on the bed turning machine^[1].

2.4 Universal testing machine design and material properties

The universal testing machine design in this study consists of three column shapes with different ribbing, while the materials used are two types.

Universal testing machine design can be seen in Figs. 3-5. Figure 3 shows a V-shaped ribbing, while Figure 4 shows an X-shaped ribbing, and Figure 5 shows a Box-shaped ribbing (without ribbing).

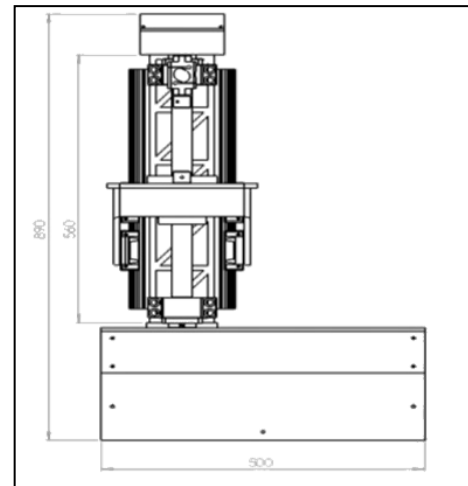


Figure 3. V-model ribbing of a universal testing machine.

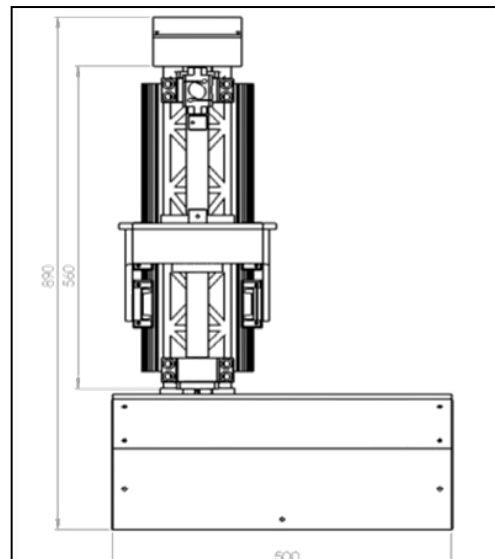


Figure 4. X Model ribbing of the universal testing machine.

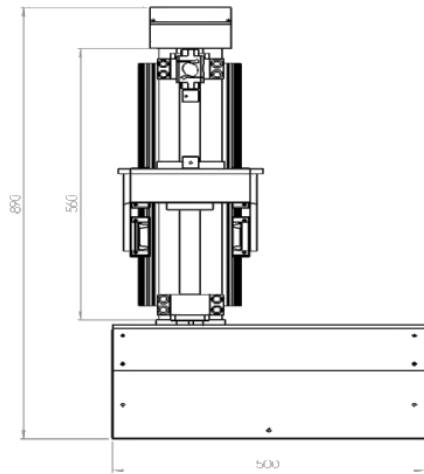


Figure 5. Box Model ribbing of the universal testing machine.

The materials used are SS400 and S45C, as shown in Table 1.

Table 1. Properties of material for structure

No.	Type of Material	Properties	Value
1	AISI 1010	Elastic Modulus	2×10^5 (MPa)
		Yield strength	180 (MPa)
		Poisson ratio	0.29
2	AISI 1045	Elastic Modulus	2.05×10^5 (MPa)
		Yield strength	530 (MPa)
		Poisson ratio	0.29

2.5 Universal testing machine modeling using FEM

The creation of a universal testing machine model is divided into two stages: the first, part creation, and the second, assembly (joining the parts).

The first stage of modeling begins by selecting a 2D sketch and then selecting a plane, as shown in Figure 6. The next step is to make the sketch 3D by selecting extrude, and create the rail support rod part using the same steps: creating a 2D sketch and extruding.

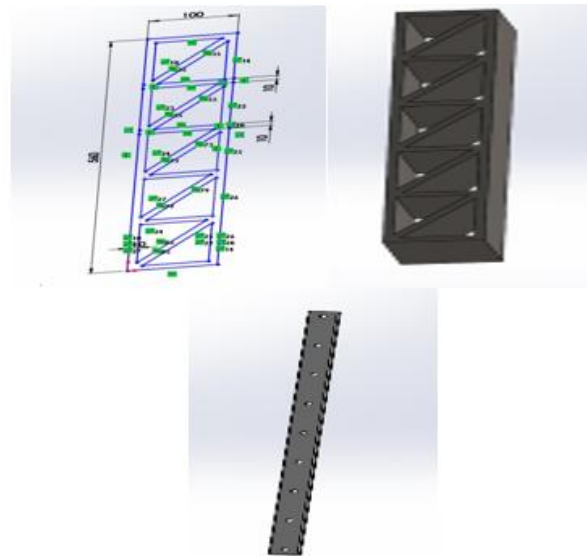


Figure 6. FEM simulation of Structure UTM.

Next, assemble all the parts using the insert components and mating. The results are shown in Figure 7.

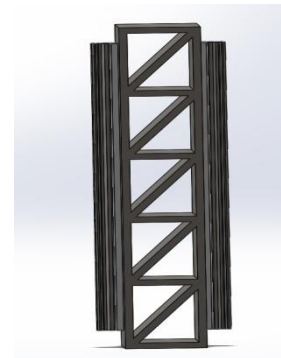


Figure 7. Assembly structure component UTM.

Table 2. Type material for the structure component

No.	Type of Material	Component
1	AISI 1010	Column
		Rail mount rod
2	AISI 1045	Head stock
		Cross head
		Table
		Column mount

2.6 Finite Element Simulation

There are three stages before the simulation: material selection, boundary conditions and loading, and finally, meshing.

Two types of materials are used for different components of the universal testing machine, including AISI 1010 and 1045 (see Table 2). The boundary conditions and loading are determined using fixed supports and roller/slider supports. The total load is used for the loading, as shown in Figure 8.

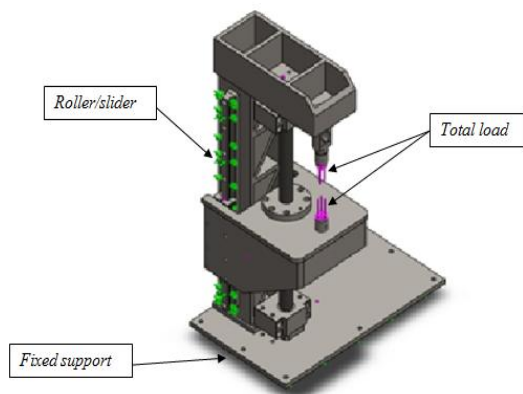


Figure 8. Boundary condition and load.

This is followed by meshing, which requires more computing power and time for smaller sizes. The results of mesh creation are shown in Figure 9. The solving process yields strain, stress, and deflection values for the model.

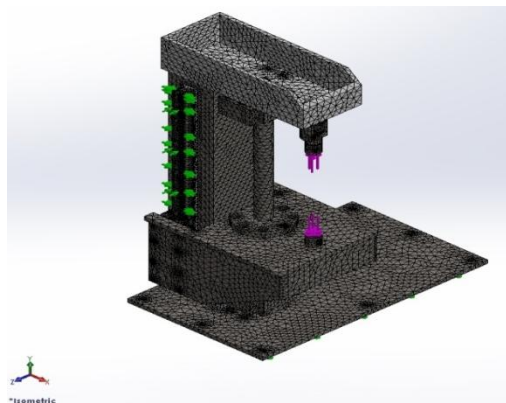


Figure 9. Meshing of the structure UTM.

3. RESULT

From the finite element method simulation, deflection and von Mises stress results were obtained, which were then used to determine the stiffness value for the universal testing machine structure model.

3.1 Simulation Results

The deflection simulation results for a load of 10,000 N and a thickness variation of 4 mm show that, for the Box model with AISI 1010 material, the maximum deflection is at the top clamp, 1,545 mm, as seen in Figure 9.

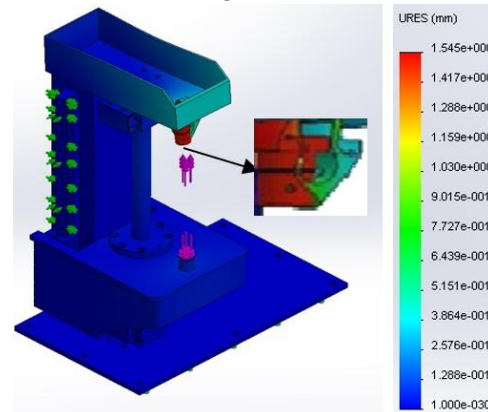


Figure 9. Deflection of the box model with a thickness of 4 mm and material AISI 1010.

For the 4 mm-thick Box model, the deflection values resulting from variations in material and rib thickness are shown in Table 3.

Table 3. Stress and stiffness value of the type material for the X model structure of the UTM

No.	Material	Thickness (mm)	Maximum Value of Deflection (mm)	Maximum Value of Stiffness (MPa)
1	AISI 1010	4	1.55	6472.49
2		6	1.48	6747.64
3		8	1.43	6978.37
4		10	1.40	7132.67
5		12	1.37	7288.63
6		14	1.35	7412.90
7		16	1.34	7473.84
8	AISI 1045	4	1.51	6631.30
9		6	1.45	6920.42
10		8	1.40	7153.08
11		10	1.37	7309.94
12		12	1.34	7468.26
13		14	1.32	7598.78
14		16	1.31	7662.84

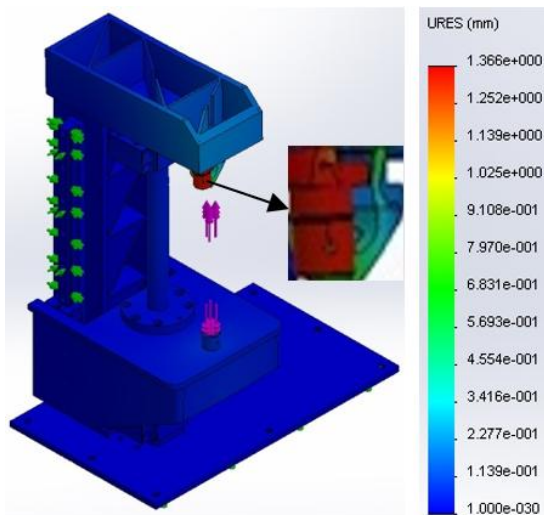


Figure 10. Deflection of the V model with a thickness of 4 mm and material AISI 1010.

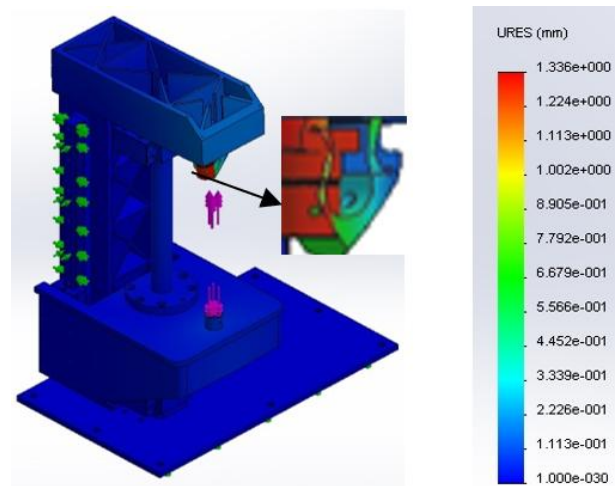


Figure 11. Deflection of the X model with thickness 4 mm and material AISI 1010.

Table 4. Stress and stiffness value of the type material for the V model structure of the UTM

No.	Material	Thickness (mm)	Maximum Value of Deflection (mm)	Maximum Value of Stiffness (MPa)
1	AISI 1010	4	1.37	7320.64
2		6	1.36	7380.07
3		8	1.35	7423.90
4		10	1.34	7451.56
5		12	1.34	7462.69
6		14	1.33	7518.80
7		16	1.33	7530.12
8	AISI 1045	4	1.33	7501.88
9		6	1.32	7564.30
10		8	1.31	7610.35
11		10	1.31	7639.42
12		12	1.31	7651.11
13		14	1.30	7710.10
14		16	1.30	7716.05

In the V model, deflection results were obtained for material and rib thicknesses ranging from 4 mm to 16 mm, with the maximum deflection of the 4 mm-thick V model with AISI 1010 material occurring at the upper chuck, 1,366 mm. For the different material variations shown, the maximum deflection and position are shown in Figure 10: the largest maximum deflection was obtained with AISI 1010 material (1,366 mm), while the smallest maximum deflection was obtained with AISI 1045 material (1,333 mm). The deflection results for the V model with variations in material and rib thickness are shown in Table 4.

Table 5. Stress and stiffness value of the type material for the X model structure of the UTM

No.	Material	Thickness (mm)	Maximum Value of Deflection (mm)	Maximum Value of Stiffness (MPa)
1	AISI 1010	4	1.34	7485.03
2		6	1.33	7547.17
3		8	1.31	7621.95
4		10	1.31	7645.26
5		12	1.31	7616.15
6		14	1.30	7716.05
7		16	1.30	7704.16
8	AISI 1045	4	1.30	7674.60
9		6	1.29	7733.95
10		8	1.28	7812.50
11		10	1.28	7836.99
12		12	1.28	7812.50
13		14	1.26	7911.39
14		16	1.26	7936.51

Furthermore, for model X, deflection results were obtained for a 4 mm thickness with AISI 1010 material, as shown in Figure 11, where the maximum deflection is observed in the chuck at 1,336 mm. Model X is 4 mm thick and is made of a variety of materials, as shown in Figure 11, where the maximum deflection is found in AISI 1010 at 1,336 mm and the minimum in AISI 1045 at 1,303 mm. The deflection results for model X with various materials and rib thicknesses are shown in Table 5.

To obtain the stiffness value for the universal testing machine structure, equation 2.1 is used. The results of the stiffness calculations for all models with AISI 1010 and AISI 1045 are shown in Table 6.

Table 6. Stress and stiffness value of the type material for the X model structure of the UTM

No.	Model	Thickness (mm)	Maximum Value of Stiffness (MPa)	
			AISI 1010	AISI 1045
1	BOX	4	6472.49	6631.30
2		6	6747.64	6920.42
3		8	6978.37	7153.08
4		10	7132.67	7309.94
5		12	7288.63	7468.26
6		14	7412.90	7598.78
7		16	7473.84	7662.84
8	V	4	7320.64	7501.88
9		6	7380.07	7564.30
10		8	7423.90	7610.35
11		10	7451.56	7639.42
12		12	7462.69	7651.11
13		14	7518.80	7710.10
14		16	7530.12	7716.05
15	X	4	7485.03	7674.60
16		6	7547.17	7733.95
17		8	7621.95	7812.50
18		10	7645.26	7836.99
19		12	7616.15	7812.50
20		14	7716.05	7911.39
21		16	7704.16	7936.51

4. DISCUSSIONS

The difference in deflection values is due to differences in ribbing and thickness models, where deflection values are influenced by force, length, elastic modulus, and moment of inertia in the ribbing model.

The obtained deflection and stress simulation results were used to calculate the stiffness values of the universal testing machine structure using Equation 2.1. The results are shown in Table 3-6. The smallest stiffness value for the AISI 1010 material is 6472.49 N/mm for the 4 mm-thick Box model, and the largest is 7751.94 N/mm for the 16 mm-thick X model (see Table 6). The smallest stiffness value for the AISI 1045 material is 6631.30 N/mm for the 4 mm thick Box model, and the largest is 7936.51 N/mm for the X 16 mm model.

From the results obtained in the form of maximum deflection and stiffness values where in the Box model, V model, and X model with variations in ribbing thickness and material have the same phenomenon in the form of maximum deflection occurring in the chuck and the smaller the ribbing thickness, the greater the deflection value that occurs so that the stiffness will be smaller and vice versa, the thicker the ribbing, the smaller the

deflection value that occurs so that the stiffness is greater.

5. CONCLUSIONS

The conclusions obtained are the ribbing design for the 1-ton-capacity universal testing machine structure using the Box, V, and X models. The largest deflection value was obtained in the Box model with a thickness of 4 mm using AISI 1010 material, while the smallest was obtained in the X model with a thickness of 16 mm using AISI 1045 material. The lowest stiffness value is in the Box model, with a thickness of 4 mm and AISI 1010 material, at 6472.49 N/mm, while the highest is in the X model, with a thickness of 16 mm and AISI 1045 material, at 12345.00 N/mm.

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