Performance Evaluation of a Designed Simple Interlocking Tile Blocks Machine

Ejiroghene Kelly Orhorhoro[1]*, Joel Oluwayomi Oyejide[2], David Atadious[3]
[1]Department of Mechanical Engineering, College of Engineering, Igbinedion University, Okada, Nigeria
[2]Department of Mechanical Engineering, Federal University of Petroleum Resources, Effurun, Nigeria
[3]Department of Mechanical Engineering, Petroleum Training Institute, Effurun, Nigeria
*Corresponding Author: ejiroghene.orhorhoro@iuokada.edu.ng

Abstract

Interlocking tile blocks have been extensively used in several countries for providing pavement in areas where conventional types of construction are less durable due to operational and environmental constraints. In this paper, we carried out performance evaluation on a designed simple interlocking tile blocks machine. The machine was designed, constructed, and used to produce samples of interlocking tile blocks. The produced samples were tested for compression strength using non-destructive testing. Computer Aided Design and failure analysis were carried out on selected part of the machine using SOLIDWORK 2017 version. The results obtained show that an average compressive strength of 52.16MPa, average production time of 12.21sec, and average destructive force of 2083.429KN were achieved. Besides, the compressive strength increase and decrease with aging of the interlocking tile blocks with optimum and minimum values obtained in day 28 and day 2 respectively. The outcome of the Von-Mises failure criteria showed that the Von-Mises stress is less than the yielding stress, thus the design is safe.

Keywords: Interlocking tiles blocks, performance, compressive strength, simple machine, Von-Mises failure criteria

1. Introduction

Ccontinuous growth in human population brings about the need for construction of roads, houses, parks, walkways, etc. One of the basic and essential needs for human being is good shelter. But, irrespective of the significance of shelter, most people do not have access to one, and this common occurrence is most frequent in under-develop and developing countries. There is an estimated deficit of between 17 and 18 million housing units in Nigeria in 2012 (Montgomery, 2002; Chuku, 2014). Besides, the general worldwide trend towards beautification of city pavements, and the rising cost of bitumen as a paving material couple with the rapid increase in construction and maintenance cost have encouraged designers to alternate paving material such as interlocking tiles blocks (ITBs) [Shahbhang, and Rao, 1970, Olusegun, et al., 2011, Yakubu, and Umar, 2015]. Strength, durability and beautifully pleasing surface have made ITBs an ideal pavement material for many commercial, municipal and industrial applications. Research work had shown that development and refinement of ITBs technique have been going on in many countries such as Argentina, Australia, Canada, France, Netherland, UK and USA. Interlocking tile blocks is now a standard materials for pavement in Europe, where over 100,000,000 m^2 are placed annually (Brožovský, et al., 2005; Wong, et al., 2012; Ajao, et al., 2016). Above and beyond, one of the major and fast growing industries across the globe is the construction industries. The construction industry is not only labour-intensive but is equally conducted in a dangerous manner; thereby necessitating the mechanization of the sector. With uninterrupted growth in the construction industries, contractors have no choice other than to increase their construction works with quality materials which is vital in the competitive market. The construction industries in most countries amounts to 10–20% of the Gross National Product (GNP) [Elattar, 2008] making it the largest economic employing sector. Figure (1) shows a pavement constructed with ITBs.

Figure 1 Interlocking Tile Blocks Pavement

Large proportion of recent construction work is done with ITBs. Interlocking tiles blocks have been extensively used in a number of countries for a specialized problem-solving technique, for providing pavement in areas where conventional types of construction are less durable due to many operational and environmental constraints (Nejad, and Shadravan, 2010; Akelere and Akhire, 2013; Mahesha, and Sree, 2014). Interlocking tiles blocks technology is widely use in Nigeria for building and construction works such as footpaths, parking areas, minor roads, street, etc. It is also adopted extensively in different uses where the conventional construction of pavement using hot bituminous mix or cement concrete technology is not feasible or desirable. Properly designed and constructed interlocking tiles blocks give excellent performance when applied at locations where conventional systems have lower service life due to a number of geological, traffic, environmental and operational constraints (Muraleedharan, et al., 1997; Tighe, and Chung, 2004). Many number of such applications for light, medium, and heavy traffic conditions are currently in practice around the world (Panda, and Ghosh, 1999; Soutsos, et al., 2011; Ashok,et al., 2015; Wuguang, et al., 2016). Table 1 shows the summary of the application of light, medium, and heavy usage of ITBs.

Table 1 Light, Medium, and Heavy Application of Interlocking Tiles (Sudip, 2008)

Light Application	Medium Application	Heavy Application
Walkways, and sidewalks	Hotels driveway	Inland
Swimming pool deck	Amusement Parks	Service station
Terraces/roof tops	Holiday Resorts	Factory compound/floors
Pedestrian crosswalk	Railway stations	Airfield runway
Jogging track	Parking lots	Bus terminals
Pavements/footpaths	Exhibition grounds	Ware houses
Patios	Farmhouse-driveway	Loading docks/ramps

Currently, ITBs are easily made by the use of machinery. Different types of machines use different techniques to make tiles. But due to high importation cost, ITBs are produced in Nigeria via traditional method. Considering the continuous growth in the construction industries couple with the difficult tasks in producing ITBs traditionally, we decided to design a low cost and affordable simple ITBs machine.

2. Materials and Method

One of the main objectives of this project work is to design a low cost simple ITBs machine built from locally available materials in Nigeria. The main materials used for the design of the ITBs machine includes: mild steel sheets, angle bars, steel pipes, sand, portland cement, water, compression testing machine, shovels.

2.1 Description of Machine Parts and Functions

The simple ITBs machine consists of the following parts; the main frame, mould, a helical cylindrical tension spring, a piston rod, a base plate, and a hydraulic system incorporated with lever.

2.1.1 The Main Frame and Mould

The main frame was made from 75mm x 10mm flat bar and 40mm x 50mm angle bars of various length, all welded together to produce a frame of dimension 1200mm × 800mm × 500mm. The ITBs mould is located at the lower part of the frame and is made from 10mm thick mild steel. The mould has the following functions; compresses loaded material which gives essence to press, and also gives the tiles its basic three dimensional shapes.

2.1.2 Helical Cylindrical Tension Spring

There are two helical tension springs attached on both side of the frame. Steel wire of thickness 4mm is coiled to form a spring with free spring length (L_o) of 400mm. The helical cylindrical tension spring helps to retract the piston after compression and extrusion process. It equally stabilizes the piston, maintaining a straight path into the compression chamber.

2.1.3 Piston Rod

The piston rod is made of mild steel, 20mm diameter solid shaft, and has a full length of 200mm. It is used for compression, and for ejection of compressed tiles from the mould.

2.1.4 Base Plate

The base plate is a rectangular structure made of mild steel with a thickness of 4mm. It has an area of 300mm × 200mm. It is a platform upon which the mould sits.

2.1.5 Hydraulic System

The hydraulic system serves as a mechanism used in transmitting force/pressure. The hydraulic piston is pushed in a downward stroke, transmitting an enormous force to facilitate compaction of the material.

2.2 Design Consideration

The design considerations that guide in the generation of the concepts that satisfy the functional requirement include;

i. The size of the ITBs (i.e., 250mm x 160mm x 100mm)

ii. The compaction/compression pressure of the machine

iii. Materials used

iv. Cost of the machine

v. Maintenance and environment in which the machine will be used

2.3 Design Requirements

The following design requirements were drawn;

i. Stress acting on piston

ii. Mould design

iii. Compression ratio

iv. Compression force

2.4 Detailed Design

2.4.1 Degree of Freedom of the Mechanism

The free body diagram (FBD) of the lever and compression unit of the ITBs machine is shown in Figure 2. The diagram shows all links and joints present in the review component parts. A mechanism is said to be constraint and movable if its degree of freedom is equal to unit (Khurmi, and Gupta, 2006).

Using Grubbler criterion,

$$F = 3(n-1) - 2j \quad (1)$$

2.4.2 The Lever Handle

This is the mechanism through which compression force is applied, creating pressure necessary for the compression and extrusion process of form interlocking tiles blocks.

$$F_c = RCos\theta = mgcos\theta \quad (2)$$

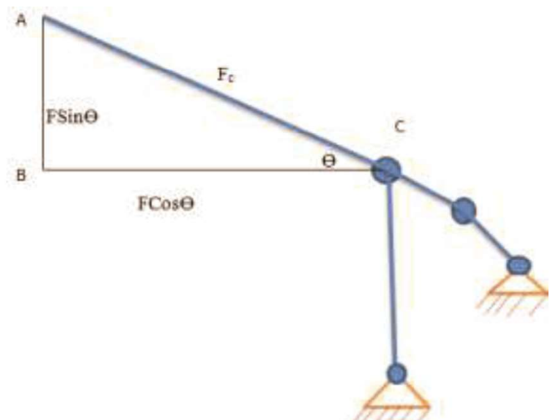


Figure 2 Free Body Diagram of Lever and Compression Unit

2.4.3 Weight of Compression Piston

The piston rod is made of mild steel, 20mm diameter solid shaft with a full length of 200mm. The choice of material selection was based on strength and toughness.

$$W_p = M_p g \quad (4)$$

2.4.4. The Helical Tension Spring

A cylindrical helical tension spring was used as a retraction mechanism for the compression piston.

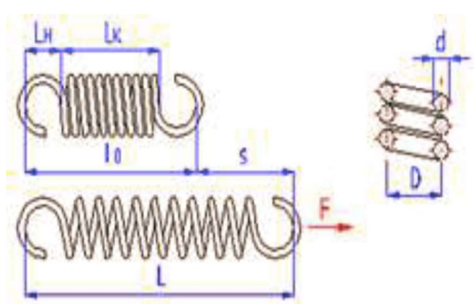


Figure 3 Tension Spring

Equation 5-Equation 7 were used to calculate the spring tension (Ryder, 2002)

$$K = \frac{G d^4}{8 N D^3} \quad (5)$$

$$D = \frac{D_i + D_o}{2} \quad (6)$$

The tensional force acting on the spring is given by Eq. (7)

$$F_T = -kx \quad (7)$$

2.4.5 Base Plate

The base plate is a rectangular structure made of mild steel; it has an area of 280mm × 180mm (Figure 4).

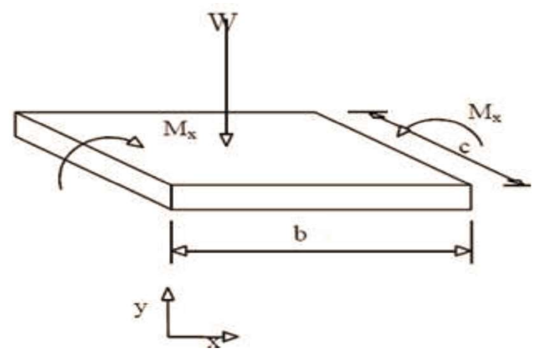


Figure 4 Base plate

Bending of the plate takes place in one direction only (i.e., y-direction). The maximum bending moment (M_{max}) is given by Eq. (8).

$$M_{max} = \frac{5wb^2}{12} \quad (8)$$

$$\sigma_{max} = \frac{M_{max} \times \frac{t_b}{2}}{\left(\frac{1}{12}\right) t_b^2} \quad (9)$$

The isometric model view of the simple ITBs machine is shown in Figure 5.

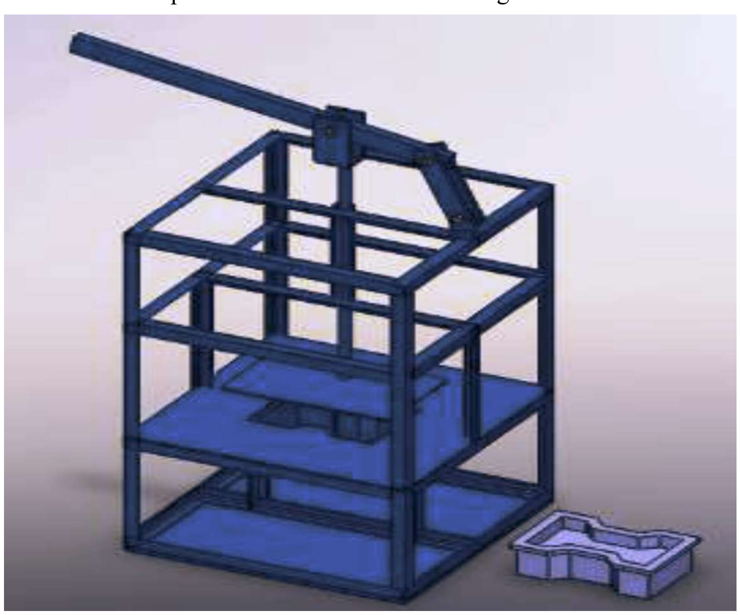


Figure 5 Isometric model view of the simple interlocking tile blocks(ITBs) machine

2.4.6 Von Mises Static Failure Analysis

Using SOLIDWORKS 2017 version, detailed Computer Aided Design (CAD) of the machine and failure analysis of selected part of the machine (i.e., piston rod and mould) using Von-Mises criteria were carried out. According to Von-Mises failure criteria, yielding of a ductile material commence when the second deviatoric stress invariants reaches a critical value. In other words, failure will only occur when the energy of distortion reaches the same energy for yield/failure in uniaxial tension (Ryder, 2002). Mathematically, Von Mises failure criterion is given by Eq. (10).

$$\left[\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}\right] = \sigma_v \qquad (10)$$

The failure condition is given by Eq. (11)

$$\sigma_v = \sigma_y \qquad (11)$$

The model information and material properties is shown in Table 2

Table 2 Model Information and Material Properties

Model information and material properties	
Model References  Cut Extrude2 	Name: Mild steel Model type: Linear Elastic Isotropic Default failure criterion: Max Von Mises Stress Yield strength: 2.20594e+008 N/m^2 Tensile strength: 3.99826e+008 N/m^2 Elastic modulus: 2.1e+011 N/m^2 Poisson ratio: 0.28 Mass density: 7800 kg/m^3 Shear modulus: 7.9e+010 N/m^2 Thermal expansion coefficient: 1.3e-005 /Kelvin Mass:5.02231 kg Volume:0.000643886 m^3 Density:7800 kg/m^3 Weight:49.2186 N
Fillet1 	Mass:10.2231 kg Volume:0.00131066 m^3 Density:7800 kg/m^3 Weight:100.186 N

3. Results and Discussion

The degree of freedom was obtained as 1. This implies the lever system through which compression force is applied is constraint and movable. The machine was fabricated and experimental test was carried out to evaluate the performance of the machine. In evaluating the machine, the machine was used to produce interlocking tile blocks. The produced ITBs were 250mm in length, 160mm in width, and 100mm in thickness. The production time, destructive force, and compressive strength of the produced samples were determined (Table 3). A non-destructive testing (NDT) was carried out to determine the load at failure. The Ultrasonic Flaw Detection (UFD) was used. This method detects surface and internal flaws, and it makes use of echo sounding techniques. The non-destructive test was carried out in interval of two days and it lasted for twenty eight days. The relationship between compression strength, destructive force, and required area of compression is given by Eq. (12).

$$C_s = \frac{F_D}{A} \qquad (12)$$

Table 3 Results of Performance Test

S/N	Days	Production Time (s)	Destructive force (KN)	Required area (m^2)	Compressive Strength (MPa)
1	2	12	1802	0.04	45.05
2	4	13	1880	0.04	47.00
3	6	12	1946	0.04	48.65
4	8	13	2054	0.04	51.35
5	10	13	2078	0.04	51.95
6	12	12	2080	0.04	52.00
7	14	13	2114	0.04	52.85
8	16	11	2122	0.04	53.05
9	18	12	2154	0.04	53.85
10	20	13	2160	0.04	54.00
11	22	12	2170	0.04	54.25
12	24	11	2182	0.04	54.55
13	26	12	2200	0.04	55.00
14	28	12	2226	0.04	55.65
∑	28	171	29168	0.56	730.2
Ave.	2	12.21	2083.429	0.04	52.16

The compressive strength of the produced samples was observed to increase with increasing aging. The optimum compressive strength was achieved in day 28 and minimum compressive strength on the second day. The results of the average as shown in Figure 6 reveal that an average compressive strength of 52.16MPa was obtained. It took the machine an average production time of 12.21seconds. To further evaluate the interlocking tile blocks for performance, the average load required to destroy the ITBs was determined and obtained as 2083.429KN.

Failure analysis was carried out on the selected part of the machine using Von-Mises criteria. Table 4 shows the load and fixture of the resultant force components gotten from impact of the piston rod on the ITBs mould former. The resultant force was obtained from the SolidWord CAD simulation as 1.414N.

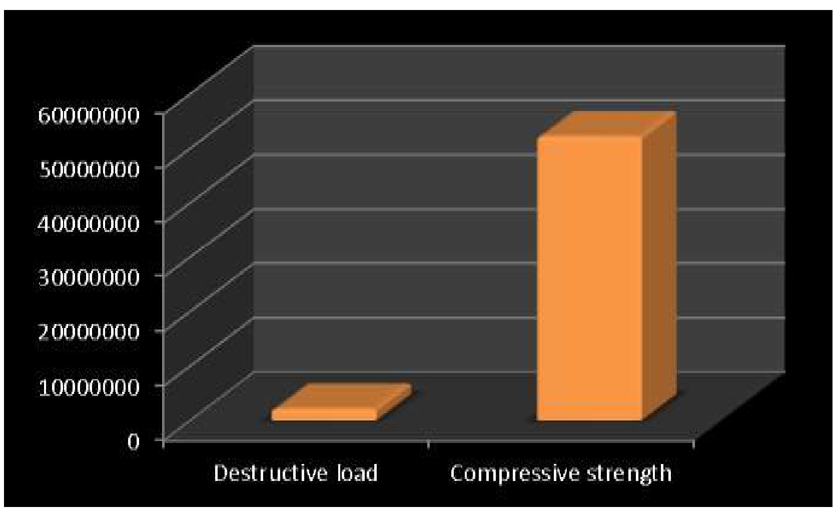


Figure 6 Average Compressive Strength and Destructive Force

Table 3 Load and Fixture of the Resultant Force Components

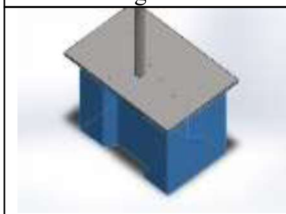
Fixture image	Fixture Name	Fixture Detail		
	Fixed1	Entities: 13Faces Type: Fixed geometry		
Resultant forces				
Components	X	Y	Z	Resultants
Reaction force(KN)	-8.62	9.99	-5.08	1.414
Reaction Moment(Nm)	0	0	0	

Figure 7 shows the solid mesh, while Figure 8 show the displacement analysis. The strain and Von-Mises stress analysis is shown in Figure 9 and Figure 10. The results of the maximum displacement was 1.38439e-008mm at node of 10714, while the minimum displacement was 1.000e-030mm at node of 7842. The results obtained from the strain analysis shown that a maximum strain of 1.057e-009, and a minimum strain of 0.000e+00N/m^2 were obtained. A maximum Von-Mises stress of 308,626N/m^2 at node 12764 and the minimum Von-Mises stresses of 0N/m^2 at node 7900 were obtained. The yield stress of the material was found to be 220,594,000.00N/m^2. Thus, the design is safe. For the design to be unsave, the Von-Mises stress must be equal or greater than the yield stress (Ryder, 2002).

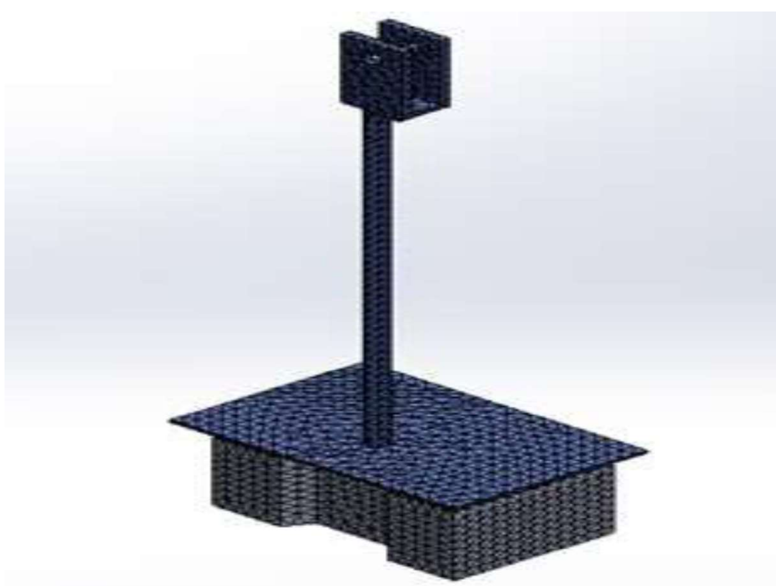


Figure 7 Solid mesh

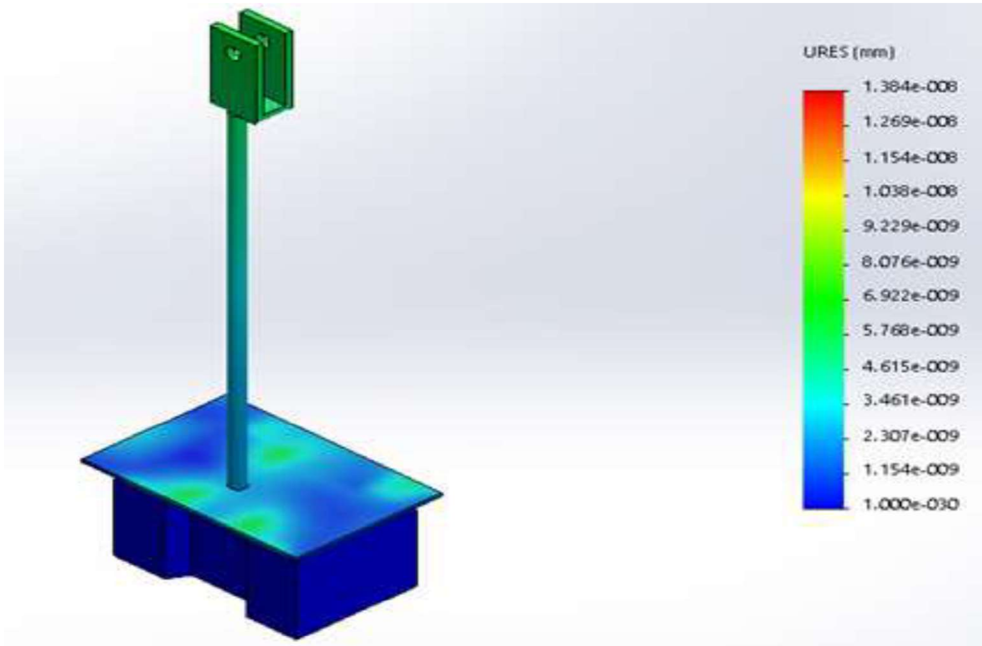


Figure 8 Displacement analysis

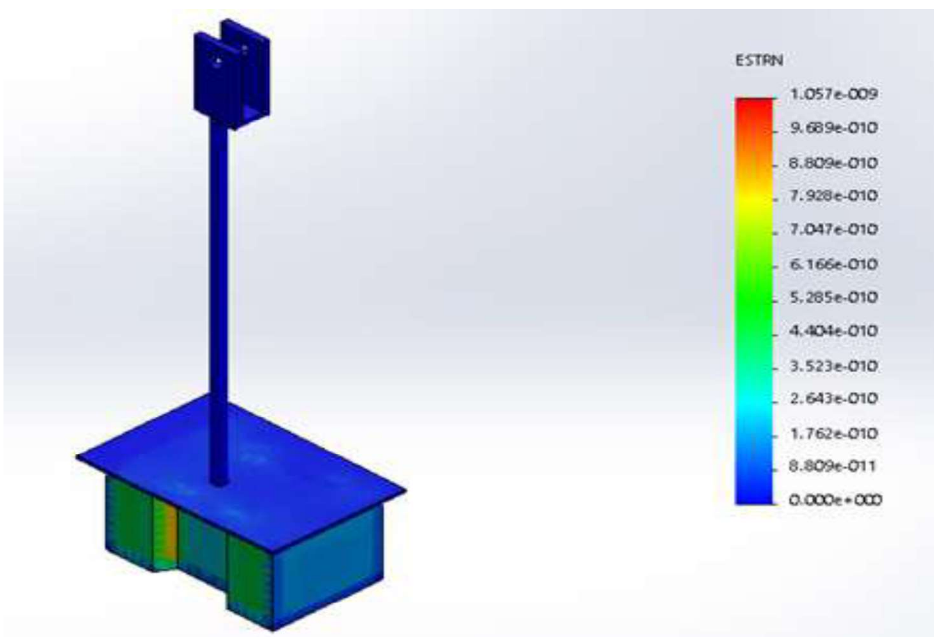


Figure 9 Strain Analysis

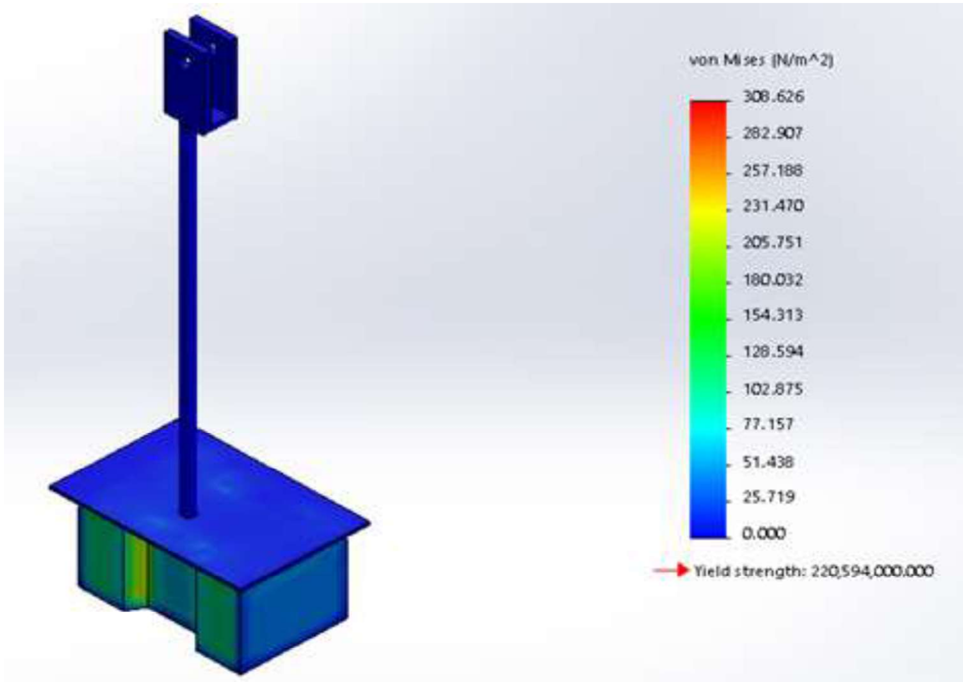


Figure 10 Result of Von-Mises stress

4. Conclusions

In this research work, we successfully designed a simple interlocking tile blocks machine. Performance evaluation was carried out on the machine and the results obtained indicated that the machine performance was satisfactory. The results of non-destructive test carried out on produced ITBs samples reveal that the product can withstand enough strength without failure. Furthermore, the Von-Mises stress was less than the yield stress that can cause deformation of the machine, thus, the designed is safe.

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