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Solid Works Design and Development of Indigineous Wear Testing Machine

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Abstract: *As a result of damages caused by wear, it becomes imperative that the wear components be monitored to estimate the intensity of wear, hence the design and fabrication of a wear testing machine for use in the materials science laboratory for the evaluation of wear. SOLIDWORKS design analysis estimated specifications were 220MN/m^2, 399.8MN/m^2, 98N, 3264.4N, 341MN/m^2 and 83.54MN/m^2 for yield strength, tensile strength, force exerted by specimen weight, cumulative resultant force, minimum shaft static stress and static displacement respectively. The equipment is used to measure the rate of wear of a high speed steel (HSS) chiseled mouth tool, to react against various materials (brass, stainless steel, mild steel, aluminum and Teflon) with the circular discs rotating against each of them. The volume of wear debris of the discs varies with time, surface contact and relative displacement that is, the pressure applied by the cutting tool. The average volume of wear after specific time interval of 30s, is given for each materials; brass (2.84cm^3), Stainless steel (1.57cm^3), Mild Steel (3.35cm^3), Aluminum (15.67cm^3), and Teflon, (63.89cm^3). This shows that the rate of wear differs with the type of materials in use. At the end of the experiment for specific time of 150s at 24.5N spring loaded, the result of wear intensity tested for mild steel, stainless steel and aluminum respectively is given as 1:166:12.5 as against 1:2.13:10 standard ratio with the machine efficiency estimated to be 86.6 %. This shows that the machine is highly dependable for estimating wear intensity of material.*

Keywords: *Development, Hardness, Intensity, machine, material, Solid works, Wear*

1. INTRODUCTION

The deterioration of surfaces is awfully a factual problem in many industries. In material science, wear is the erosion of material from a solid surface by the action of another solid. The study of the processes of wear is part of the discipline of tribology. The special effects of wear, which are extremely expensive, can be repaired by means of welding surfacing with specialized welding filter metals using the normal welding. Welding processes is used to replace worn metal with metal that can provide more satisfactory wear resistance property than the original. Hard facing applies a coating for the purpose of reducing wear or loss of material by abrasion, impact, erosion, cavitations etc. in order to properly select a hard facing alloy for a specific requirement it is necessary to understand the wear that has occurred and what caused the metal deterioration. (Wikipedia, 2008)

Wear is defined as loss of dimension from plastic deformation, although wear may occur, and there may be no material removal. This definition also include impact wear, where there is no sliding motion, cavitations, where the counter body is fluid and corrosion, where the damage is due to chemical reaction rather than mechanical action. Wear can also be defined as a process in which interaction of the surface or bounding faces of a solid with its working environment results in dimensional loss of the solid, with its without loss of material. Aspects of the working environment which affect wear include loads (such as unidirectional sliding, reciprocating, rolling and impact loads), speed, temperature, type of counter body (solid, liquid or gas) and type of contact (single phase or multiphase in which the phases involved can be liquid plus solid particles plus gas bubbles) (Godfrey, 1980).

The different types of wear are Adhesive wear, Abrasive wear, Corrosion wear, Surface fatigue wear, Fretting wear, Oxidation wear, Compression wear, Cavitations wear, Impact wear and Erosion wear. In the results of standard wear tests, the loss of material during wear is expressed in terms of volume.

The volume loss gives a true picture than weight loss particularly when comparing the wear resistance properties of material with large differences in density. The working life of an engineering component is over when the losses dimensionally exceed the specified tolerance limits. Wear, along with other aging process such as fatigue, creep, and fracture toughness causes progressive degradation of material with time, leading to failure of material at an advance age. Under normal operating parameters, the property changes during usage normally occur in three different stages as follows:

1) Primary or early stage or run-in period where rate of change can be high.
2) Most of the useful or working life of the component is comprised in this stage. Secondary or mid-age process is maintained.
3) Tertiary or old-age stage, where a high rate of aging leads to rapid failure.

With increasing severity of environmental conditions such as higher temperatures, strain rates, stress and sliding velocities, the secondary stage is shortened and tends to merge with the tertiary stage, thus drastically reducing the working life. Surface engineering processes such as surface hardening, heat treatment processes, welding, lubrication etc. are used to minimize wear and extend working life of materials.

Materials to be tested are made in circular disc with inner core to be mounted on the rotating shaft against a sample pin with chisel edge tip, acting tangentially or perpendicular to test disc materials. The scratches on the body of the material are observed for a specified time. The rate of the wear debris is measured with a digital weighing equipment to determine the volume of the wear debris, which is directly proportional to the wear resistance of various materials.

Tribology is the science and technology of interacting surfaces in relative motion. It includes the study and application of the principles of friction, lubrication and wears (Wikipedia, 2009).

Every machine in which there is transmission of motion definitely contain components that are in relative motion with one another, and every material component that is in relative motion with another components is bound to experience wear. Wear could be described as the progressive loss of material substance from the surface of a body as a result of its relative motions at the surface with one another body.

As a result of damages caused by wear it becomes important that the wear of the components be monitored to estimate the intensity of wear. There is also various contamination monitoring techniques used in identifying whole – engine wear. In the course of lubricating, monitoring, the debris transported by the lubricating oil and fluid is use to recognize the part that is deteriorating and likewise to know the rate of deterioration (Lilly, 1984). Wear is the gradual change in dimension of a body subjected to friction (Lakhtin, 1990) is detrimental and as such in many applications of few thousands of an inch of wear can cause an entire machine to fail (Brandt 1985).

This work analyzes the wear resistance of various metallic and one nonmetallic materials e.g. brass, stainless steel, mild steel, aluminum, and Teflon, the different types of wear encountered at different environmental conditions. It also shows the effects of wear and friction on metals and lubrication, surfacing and hard facing as means of eliminating or minimizing them. It gives detailed design analysis of different component parts such as pulley, belt drive, and shaft diameter of the wear testing machine. It also analyzes the performance evaluation of the machine which serves as a method of comparison of rates of wear in the different metallic materials over a specified period of time and the results obtained are used to obtain the wear resistance ratio of each material. The significant of this work will lead to the elimination of frequent breakdown of machine parts, reduction in loss of dimension from plastic deformation, reduction in machine element malfunction and reduction in the cost of replacement or repair of worn out parts.

This work is targeted towards the development and performance evaluation of the wear testing machine, which could be used to estimate the wear resistance of various materials.

2. METHODOLOGY

2.1. Project Description

The cutting tool used was of HSS material welded to a 19mm diameter bolt and grinded to form a chisel mouth tip. The tool holder was designed easy tightened and removal. The shaft key way of 7 × 5mm was machined to accommodate more circular disc. The table 0.4 × 0.6m by 0.05m of mild steel material was drilled through 30mm from one end of the table frame for easy traverse movement of the tool holder. The table welded to the side angle bar irons of 0.05 ×0.05m by 0.005m in thickness to serves as the frame and then to same angle bars of 100mm as the legs. Four holes of 10mm diameter are drilled on the machine table for mounting the electric motor of 1 horse power with bolts and nuts. Two square bar irons 0.05 × 0.05m by 0.005m in thickness are welded at angle 90^0 to each other and then welded to the machine table which is then drilled on top to allow for the mounting of pillow bearings of 25mm diameter. The shaft of 25mm is made to pass through the bearing carrying the discs, pulley. Table frames that accommodate the bearing are welded together while the belt connects the motor pulley to the shaft through a pulley of 150mm diameter as shown in Fig. 1. The motor is connected to a source of power supply for experimentation. The detail working diagram is captured in Fig. 2.

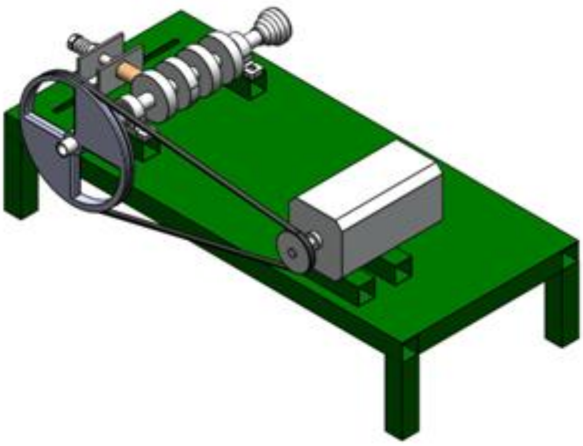
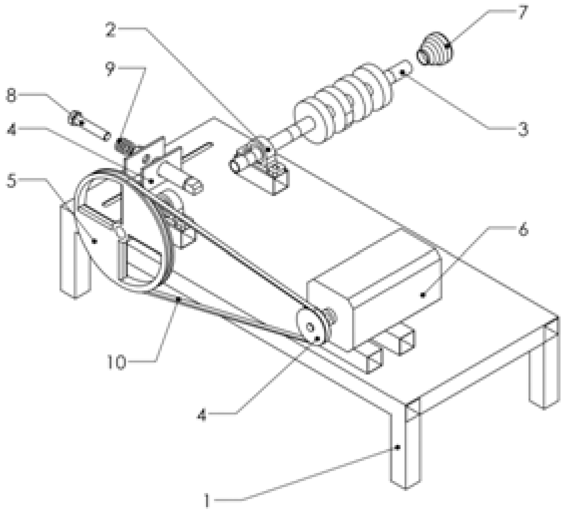
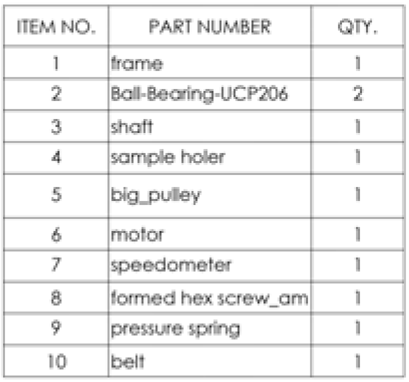


Fig1. *Isometric view of Wear Testing Machine*





ITEM NO.	PART NUMBER	QTY.
1	frame	1
2	Ball-Bearing-UCP206	2
3	shaft	1
4	sample holer	1
5	big_pulley	1
6	motor	1
7	speedometer	1
8	formed hex screw_am	1
9	pressure spring	1
10	belt	1

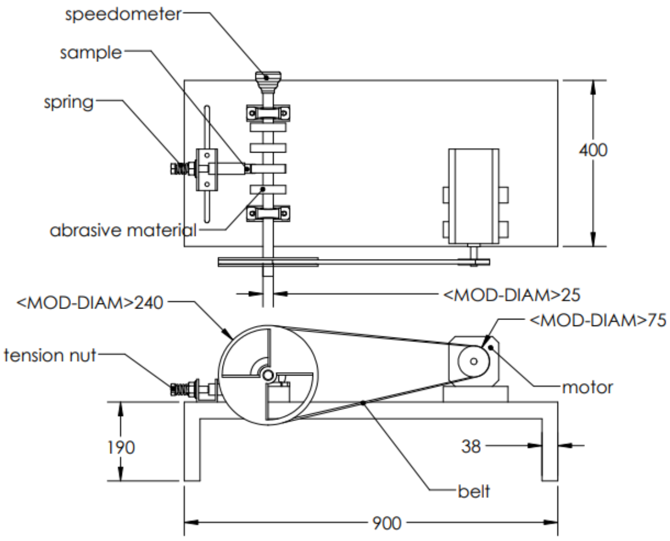


Fig2. *Wear Testing Machine Working Diagram*

2.2. Design of Machine Elements

Design Analysis of Shaft Pulley: The shaft pulley diameter was estimated as 150mm using the speed ratio with allowances for slippages in equation 1 as given by Deutschman, (1995) and Ejiko et. al., (2010).

$$I = \frac{W_1}{W_2} = \frac{d_1}{d_2}(1 - E) \tag{1}$$

Where E = slipping coefficient, ranging from 0.005-0.03, I = the speed ratio, W_1= motor speed and W_2 is the expected shaft speed.

Design Analysis of Belt drive: The belt parameters were achieved through the following consideration, Diameter of motor pulley = 25 mm = 0.025m N, speed of motor pulley =3000 rev/min using equation 2 and 3 as given by Akerele and Ejiko, (2015) and Ejiko et. al., (2018a).

$$V = \frac{\pi dN}{60} \tag{2}$$

$$V = \frac{\pi \times 0.025 \times 3000}{60} = 3.953 m/s$$

$$\frac{T_1 - T_c}{T_2 - T_c} = \ell^{\mu\theta} \tag{3}$$

where

$T_c = mv^2$,

$T_{1\,=}$ tension in the tight side of belt (N),

$T_{2\,=}$ tension in the slack side of belt (N),

$T_{c\,=}$ centrifugal tension (N),

V = velocity of the belt (m/s),

μ = coefficient of friction between the belt and the sides of the groove.

θ = angle of contact (radians),

μ =0.15 (rubber on mild steel) (Aaron, 1985 and Wikipedia, 2008)

T_p = 1.59 Nm, r_p = 0.0125 m, Tension ratio = 1.6. Centre distance is estimated from

$$x = 3r_1 + r_2 \text{ or } x = 2r^2 \qquad (4)$$

(Deutshcman, 1995; Khurmi and Gupta, 2005; Ejiko et al., 2015a),

where, r_1 = radius of motor pulley. Length of Belt using Centre Distance Min = 0.1125M, L = 0.5356m = 535.6mm = 21in, Length of Belt using Centre Distance Max = 0.15M, L = 0.6017m = 601.7mm = 24in

A-23 belt is selected based on Table B – 3 shown in appendix 2, because the minimum length belt is 21 inches and the maximum length of belt is 24 inches, therefore 23 inches was selected to avoid being longer or shorter than necessary.

Actual Distance using Actual Length of Belt 769.7 ft/min

Number of belts required for the belt drive is 1

Design Analysis of Shaft The solid shaft used is transmitting power under various operating and loading conditions of tension, bending and axial loads. The torque (T_p) was determined to be 1.59N-m on the shaft from electric motor of 500watts rotating at 3000rev/min by applying equation (5)

$$T_p = \frac{P \times 1000 \times 60}{2\pi N} = \frac{9550P}{N}(Nm) \qquad (5)$$

From the bending moment diagram:

M = 44Nm

The diameter of the power shaft was determined to be 21.6mm or 0.0216m by applying the shaft design equation from Shigley and Mischke 1996 and Ejiko et. al., (2015b) and (2018b) as indicated in equation (6). However, the standard shaft diameter of 25mm or 0.025m is selected for this design

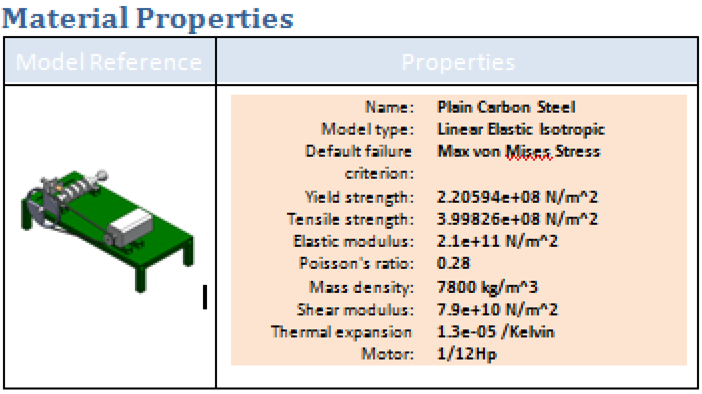
$$d = \left\{ \frac{32\lambda}{\pi} \left[(M/S_e)^2 + \frac{3}{4}(T_p/S_y)^2 \right]^{\frac{1}{2}} \right\}^{\frac{1}{3}} \qquad (6)$$

(Shigley and Mischke, 1996)

Where K = Fatigue modification factor is 0.33, λ = factor of safety is 2, S_y = yield strength is 454.74MN/m^2, S_e = Tensile strength is 88.67MN/m^2 for AISI Type metal number 1020 gradually applied load (Khurmi & Gupta, 2006)

2.3. SOLIDWORKS Analysis

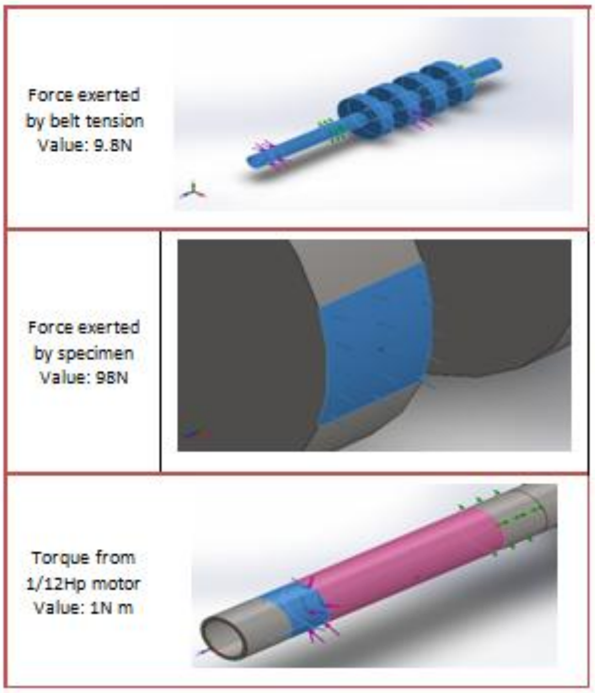
The material type considered for the analysis with the SOLIDWORKs package has the following specifications which includes name plain carbon steel as captured in Fig. 3, model type is linear Elastics Isotropic, yield strength is 220 MN/m^2, tensile strength 399.8MN/m^2 .as shown in Fig. 4 and 5. The belt exerted a tension force of 9.8 N, specimen weight exerted a force of 98 N. The bearing fixed hinge exerted forces under the X, Y, Z coordinates of 1984.81 N, -2367.69 and -1053.97 respectively with a cumulative resultant of 3264.4N. The minimum shaft static stress and static displacement were 341MN/m2 and 83.54MN/m^2 as shown in Fig. 6 to 8 which are closely related to the manually analyzed values.



Material Properties

Model Reference	Properties	
	Name:	Plain Carbon Steel
	Model type:	Linear Elastic Isotropic
	Default failure criterion:	Max von Mises Stress
	Yield strength:	2.20594e+08 N/m^2
	Tensile strength:	3.99826e+08 N/m^2
	Elastic modulus:	2.1e+11 N/m^2
	Poisson's ratio:	0.28
	Mass density:	7800 kg/m^3
	Shear modulus:	7.9e+10 N/m^2
	Thermal expansion	1.3e-05 /Kelvin
	Motor:	1/12Hp

Fig3. *Properties of Selected Materials*



Force exerted by belt tension Value: 9.8N

Force exerted by specimen Value: 98N

Torque from 1/12Hp motor Value: 1N m

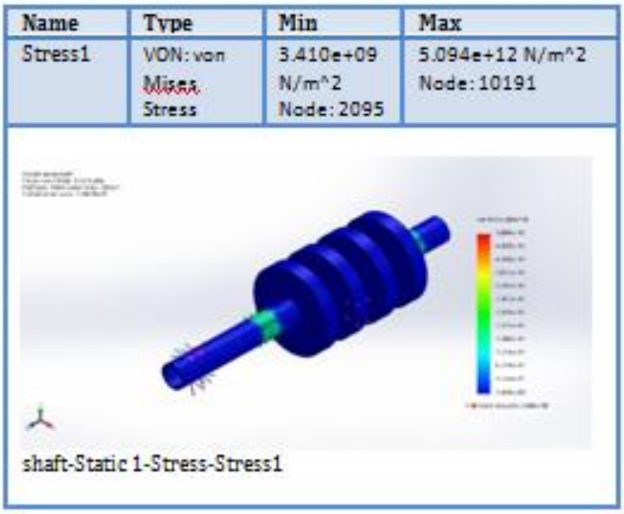
Fig4. *Torque and Force Diagram*

Fixture name	Fixture image
Fixed Hinge by bearing	

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	1984.81	-2367.69	-1053.97	3264.4

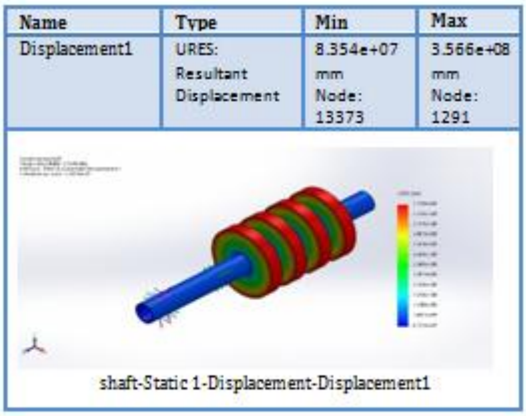
Fig5. *Force Analysis on X, Y, Z axis*



Name	Type	Min	Max
Stress1	VON: von Mises Stress	3.410e+09 N/m^2 Node: 2095	5.094e+12 N/m^2 Node: 10191

shaft-Static 1-Stress-Stress1

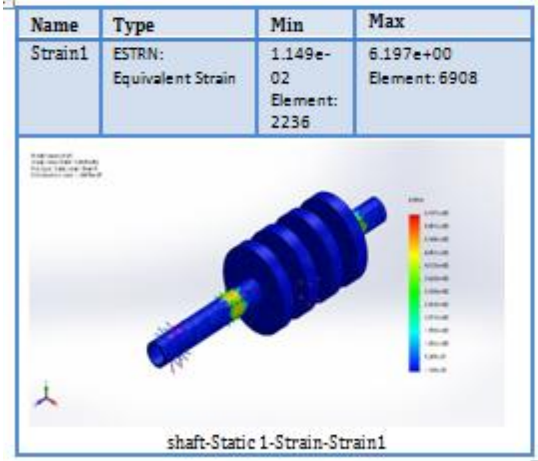
Fig6. *Max. and Min. Stress Diagram*



Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	8.354e+07 mm Node: 13373	3.566e+08 mm Node: 1291

shaft-Static 1-Displacement-Displacement1

Fig7. Max. and Min. Displacement



Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.149e-02 Element: 2236	6.197e+00 Element: 6908

shaft-Static 1-Strain-Strain1

Fig8. *Stress strain Analysis*

3. EXPERIMENTATION

The materials tested were brass, stainless steel, mild steel, aluminum and telpon (polytetrafluorethylene). The various materials to be tested are made in circular disc with inner core to be mounted on the rotating shaft against a sample pin with chisel edge tip, acting parallel on the materials (in form of discs, having inner core) scratches the body of the test piece for a specified time interval of 30s, 60s, 90s, 120s and 150s respectively. The volume of the wear debris is determined by weighting the test piece with a digital weighing equipment (Mettler PL 3000 made by Mettler instrument AGCH – 8606 Greifensee – Zurich in Switzerland) to determine the reduction in the weight of the test piece with its relative volume of the wear debris, which is used to estimate the wear resistance of various materials.

4. RESULTS AND DISCUSSION

Table 1 shows the weights of the materials measured with different weighing scales in kg, ibs, and the digital weighing equipment for a period of 150s.

Table1. *Weights of Materials Tested, Weighed on Different Scale*.

Materials	Mass (kg)	Mass (Ibs)	Mass(g) Digital
Brass	1.19	2.6	1197.5
Stainless steel	1.05	2.3	1024.28
Teflon	0.015	0.039	710.0
Mild steel	0.65	1.49	235.7
Aluminum	0.02	0.49	167.5

Table 2 shows variation in weights of the materials tested based on 150s testing time, the volume of wear (cm^3), and the volume per second (cm^3/s) for each of the material tested, which is the relationship between the load applied, Time, and wear volume removed from each samples.

4.1. Performance Evaluation

From the volume of wear debris generated as shown in Table 3 for a period of 450 seconds in conjunction with brinell hardness value a relationship was established that gives the wear ratio of the material.

Table2. *Volume of Wear Debris after the Experiment*

Materials	Volume of wear (cm^3)
Brass	2.84
Stainless Steel	1.57
Mild Steel	3.35
Aluminum	15.67
Teflon	63.89

Common Values

The values of some material Brinell hardness number (BHN) are given in Table 4 which is essential for comparism is required toward the evaluation of performance of the machine wearing effect.

Table3. *Standard Brinell Hardness number*

Materials	Hardness
Softwood (e.g pine)	1.6HBS 10/100
Hardwood	2.6 – 7.0 HBS 1.6 10/100
Aluminum	16HB
Copper	35HB
Mild Steel	120HB
18 – 8 (304) stainless steel annealed	200HB
Glass	1550HB
Hardened tool steel	1500 – 1900 HB
Rhenium diboride	4600HB
Note: Standard test conditions unless otherwise stated	

Source: *(Wikipedia, 2009)*

Table4. *Relationship between Standard Brinell Hardness number and the volume of wear debris.*

Materials	Volume of wear (cm^3)	Standard Brinell Hardness number (HB)
Brass	2.84	-
Stainless Steel	1.57	200
Mild Steel	3.35	120
Aluminum	15.67	16
Teflon	63.89	-

Relationship between volume of wear and Standard Brinell hardness number.

Based on the definition of hardness which implies the resistance to wearing effect therefore the volume of wear was taken to be inversely proportional to the hardness of the materials.

$$\therefore \text{Vol. of wear, } W \alpha \frac{1}{H} \text{ this implies that } W = \frac{k}{H} \qquad (7)$$

Table5. *Comparison of standard test Ratios against test result ratio.*

Test Ratio	Standard Ratio
1.57:3.35:15.67	0.005:0.0083:0.0625
1:2.13:10	5:8.3:62.5

Table6. *Ratio of standard test with test result.*

Materials	Test Ratio	Standard Ratio
Stainless Steel	1	1
Mild Steel	2.13	1.66
Aluminum	10	12.5

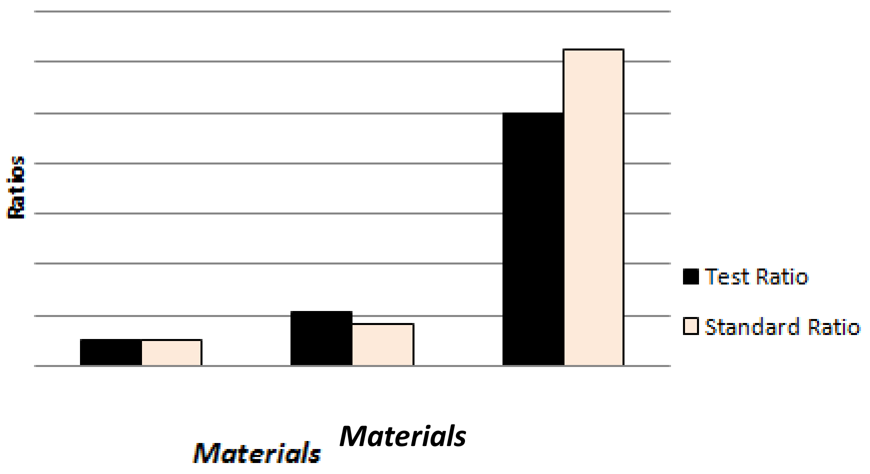


Fig. 4.2: Comparison between Standard Ratio and Test Ratio

Efficiency of the Machine

$$\% \text{ error of the results} = \frac{2.03}{15.16} = 0.134\% \text{ error} = 13.4\%$$

Percentage error = 13.4%

Efficiency = 100% - % error

∴ Efficiency. = 86.6%

The efficiency of the machine was estimated to be 86.6 %. This shows that the machine is highly dependable for estimating wear intensity of material.

5. CONCLUSION

At the end of the experiment for specific time of 150s at 24.5N spring loaded, the result of wear intensity tested for mild steel, stainless steel and aluminum respectively is given as 1:1.66:12.5 as against 1:2.13:10 standard ratio, which shows a percentage error of 13.4%. The efficiency of the machine was estimated to be 86.6 %. This shows that the machine is highly dependable for estimating wear intensity of material.

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