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Testing of the ability of fatigue test machine prototype and fatigue test for nylon and cast iron specimens

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Abstract. Fatigue life prediction for engineering material is important for predictive maintenance to support accident prevention in a high-risk equipment. The study aims to determine the ability of the machine prototype of rotating bending type fatigue test and to find out the fatigue life of Nylon and cast iron specimens. By knowing the fatigue life of a plastic and ferrous metal material, the prediction of fatigue life can be applied to a maintenance plan. The design and manufacture of rotating bending fatigue testing machines equipped with copy turning devices can be used to prepare specimens from plastic/soft metal materials, thus becoming an integrated fatigue test machine. The method used includes determining the standard size of fatigue test specimens, turning various fatigue test specimens, carrying out fatigue test specimens of nylon and cast iron materials, and analyzing the results of fatigue tests. The test results of the fatigue test machine prototype showed the ability to turn plastic and soft metal materials, and the fatigue life for Nylon 6.6 ranging from 659 to 13216 rotation for breaking the specimens at 229 to 26 MPa stresses, and for cast iron from 142 to 22863 rotation at 229 to 147 MPa stresses.

1. Introduction

Expensive prices and shortage fatigue test machines become obstacles in the fatigue test for engineering materials. The making of a prototype of fatigue test machine can support the achievement of affordable fatigue test machine prices and its existence is much needed by the polytechnic education community and medium industries.

The limitations of the fatigue test machine to encourage industry is not always to test the fatigue life of its products, including universities not necessarily provide it, because consumers do not always need fatigue life product information and the limited affordability of the machine price. So the industry does not have the obligation to test the fatigue life of its products, and some students only recognize the concept is limited to theoretical studies only if the college does not facilitate them. The educational model is inadequate for educational institutions such as polytechnics that promote a balance between theory and practice. Many accidents have claimed many victims in a society that eventually emerged a report on many factors that one cause is the material fatigue.

Fabrication of fatigue test machine prototypes have the opportunity of students to practice on the topic of fatigue test as they work in industry which in turn can always be aware that every component has certain fatigue life that must be prevented by maintenance and/or replacement before accident. Specific objectives can be achieved if the prototypes can be mass-produced so as to achieve production efficiency and affordable product prices by medium-sized industries that do not necessarily prioritize the prevention of an accident rather than simply prioritize component business without providing assurance or information on its fatigue life.

The availability of a prediction of fatigue life of a component makes a transaction with a price is realistic for its usage services, whilst the prospective consumer does not know it, the producer cannot provide information on the estimated fatigue life depending on whether it is the quality of the raw material, the production process, the usage or the loading conditions, and its operational environment. It would be different if the fatigue life prediction was reported that the fatigue test results of a component under certain conditions predicted to approach the real conditions in the field. Under these conditions, the information obtained by consumers with relevant data, so that the purchase of a component can be proportional to the benefits.

An illustration: the manufacture of an aircraft takes about 2-3 years with adequate technological support, while the operation and maintenance of aircraft for example can reach 10 to 25 years, then with one accident case, resulting in the entire investment of an aircraft will disappear instantly, regardless of the preparation of an insurance claim, so with a plane crash can make the investment turn to zero or even minus due to its impact, which may be the cause of fatigue life that is disrupted because of the passing limit of resistance of a component.

2. Related works

Fatigue tests show that failure cannot be predicted accurately, as fatigue is affected by number of cycles, force reversing fluctuations, temperature, atmospheric conditions, and material defects (inside and on surface) that include notches, inclusions, stress concentrations and inhomogeneity of materials [1]. Many mechanical components experience stressful fluctuations in their operations, resulting in fatigue failure. The design of the fatigue test machine [1] of the electric motor shaft is directly connected to the bearing and clamp specimen whose axle cannot be flexed in the event of a symmetric deflection during loading on both ends of the specimen.

The mechanical component subjected to fluctuating stresses in the fatigue test machine, resulting in failure under a tensile strength called fatigue failure. Fatigue test machines require high design costs with specimens subjected to repeated fluctuating stresses and the number of cycles is counted until the specimen breaks [2]. Fatigue test machine design requires high cost for specimen conditions subjected to repeated fluctuating stresses and simultaneously performed count the number of cycles until the specimen becomes broken.

Failure of a material fatigue is reported to cause > 75% to occur suddenly. The diameter specimens between 6 and 8 mm were loaded between 30 and 90kgs and the number of failure cycles was obtained from both the experimental methods and the theoretical calculations whose results were close. The machine has the advantage: ease of operation, maintenance, and safely to use [3]. A rotating bending on fatigue test machine design with varying bending and torsion stress has been tested and is easy to operate.

Cost ranges for typical educational fatigue testing machine was from $ 10,500 to $ 32,500. The machine is an adaptation of the R. R. Moore fatigue test machine in an industry that costs over $ 150,000. The goal is to produce an affordable and reliable machine version [4]. Special educational fatigue test machine has been made with a much cheaper price than the fatigue test machine used in industry.

Fatigue can result in a failure of > 80 percent in a repetitive load material that occurs under the tensile strength of the material. The solution of the problem knows fatigue life material from fatigue test machine. There are many types of fatigue test machines for loading on the shafts of cars that have both bending and torsion simultaneously. The development of fatigue test machine design for the combined loading of bending and torsion simultaneously with the cheaper price becomes a further consideration [5]. A proposed fatigue test machine design with combination of bending and torsion simultaneously.

From various literature reviews obtained comparators to show that: the use of flexible coupling after the electric motor is important so that loading can be given symmetrically; the loading mode is strongly influenced by the applied force source and the mechanical force is generally stable and widely used; efforts to design fatigue test machine with cheaper cost continues to be developed; load fluctuations and counts of number of cycles must be performed simultaneously during loading; the surface of the fatigue test specimen should be as smooth as possible to obtain the optimum result; the fatigue test result of a specimen is shown in the form of S-N curve; and bending and torsion variations can be applied to fatigue test machine design with easy operation.

3. Rudimentary

Fatigue of a material is caused by the cycling/alternating load, for example on bolts, springs, saw blades, bicycle pedals, and shafts [6] as examples of broken products of fatigue of a material is due to alternating loads.

The application loads cycles at constant amplitude, but the load is irregular to the time that is often encountered. Examples of impregnated loading of time are on a car steering arm as a stress fluctuation as a function of time, vibration due to roughness of the road, and due to the maneuvering of vehicles, also the load for each round of a helicopter rotor [7].

In the fatigue test machine specimen as a rotating rod by R.R. Moore is equipped with: a shutoff switch, when the specimen is broken, the shaft end of the grip moves downward, and the shutoff switch is working to break the electric current on the electric motor, revolution counter, flexible coupling, and weight load on both ball bearing and the specimen bending [8].

Standard fatigue test machine for rotating rod by R.R. Moore is by: loading of 0.05; 0.1; 0.2; 0.5; 1; 2; 5; and 10 kg; specimen rotation 500-10.000 rpm; length of standard specimen 87.3 mm, the largest tapered-end specimen diameter is 12.2 mm and at both ends of the cylindrical handle (straight shank specimen), and the center radius is 88.9-254 mm [9-10].

A material with a fatigue limit is shown as a curve that decreases with reduced cyclic stress and reaches a constant value after achieving a value of more than 10 million (10^6) cyclic. For a material without the fatigue limit is indicated by a curve which continues to decrease with decreasing cyclic stress [7].

An example of S-N curves for 1047 steel material is having a curve that decreases from cyclic stress around 500 MPa at around 10^4 cyclic decreases towards cyclic stress around 320 MPa in about 10^6 cyclic which is constant up to around 1.4×10^8 cyclic [11]. Furthermore, the example of the S-N curve for Aluminum 2014-T6 is to have a continuously decreasing curve of cyclic stress around 410 MPa at around 1.5×10^3 cyclic to cyclic stress of around 130 MPa at around 1.4x108 cyclic [11].

The results of case studies of properties and fatigue tests on steel, Aluminium and plastic show that: steel has a fatigue limit of 450 MPa in 100×10^6 cycles, Aluminium has a fatigue limit of 115 MPa in 100×10^6 cycles, and PVC plastic has a 10 MPa fatigue limit in 100×10^6 cycles, indicating that the three materials have the same fatigue life limit for different loads, or with other meanings, for the same load with different fatigue life [12].

Programming on CNC lathes has been successfully made for continuous radius type fatigue test specimens with small diameter of 9.3 mm and main diameter of 16 mm with M and G codes namely M03, G00, G01, G02, M92, M99 and M30 [13]. Program commands in a CNC type Lathe with 7 types can make fatigue test specimens based on ASTM E466-82 in the form of continuous radius cylindrical specimens from R.R. Moore which is similar to the shape of a tensile test specimen.

4. Materials and methods

The specimen materials selected in the fatigue test with standard form which is cylindrical in the middle with radius in longitudinal direction are Nylon 6.6 plastics were prepared by a copy turning devices and cast iron were prepared by using a Computerized Numerical Controlled (CNC) lathe to make radius in the longitudinal direction (along the specimen axis).

Several available fatigue test methods provide an appropriate choice for a test in which the preferred method is the design of a fatigue test machine with a rotating specimen that follows the concept of R.R. Moore. The design of a fatigue test machine using a DC motor as a rotation drive of its specimen can be changed rotation speed without using a belt-pulley mechanism. Between the electric motor shaft and the specimen drive shaft are connected to a flexible shaft using rubber from a tire of a motor vehicle

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available in the field. The flexibility of the drive shaft is to follow the flexibility of the specimen before the break, allowing the loading to be given symmetrically. Symmetric loading is possible by making two pairs of transverse shafts that are balanced on the swing construction of both ends of the specimen end using two chucks of a drill bit. The loading is given by mechanical loading of a 0.5 kg steel weight, followed by a multiple of each kg to a maximum load of 10 kg. The weighting is made of a construction that can adapt when the specimen test begins to flex. When the specimen is broken on a particular deflection, it is connected to a limit switch that can cut the current on the electric motor, so that the electric supply is up and the motor stops for rotating. The rotation of the specimen axis is counted with an encoder to records the amount of rotation achieved at one end of the shaft. With the end of a specimen rotation, the encoder recorded of the specimen rotation as a reflection of the fatigue life specimen. A number of specimens were tested for fatigue in order to plot the S-N curve as fatigue properties of a material.

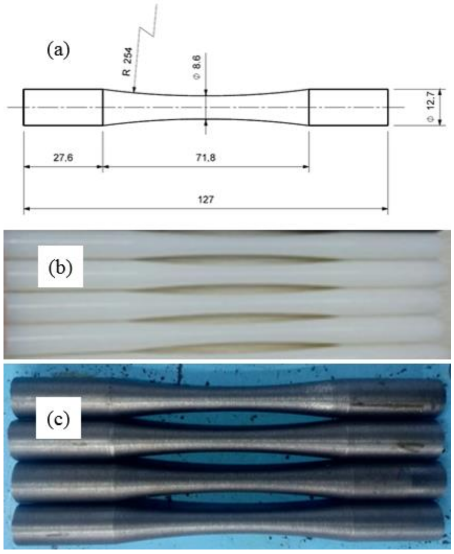

Figure 1. Fatigue test specimens: (a) Standard dimension, (b) Nylon, and (c) Cast iron.

The fatigue test specimens were derived from selected plastics of Nylon 6.6 prepared by copy turning device and cast iron specimen prepared by a CNC lathe to meet the radius shape in the longitudinal direction (R = 254mm) and achieve a smoothness of approximately N5-N6 as shown in Figure 1. The capability of the fatigue test machine is for a maximum specimen size of 130mm in length, and 13mm in diameter on both grips.

Integrated fatigue test machine using DC motor with 3 kW, 48V, speed: 3000-5000 rpm, torque: 10 Nm, and cooling: air is shown in Figure 2 [14].

Figure 2. DC electric motors 3 kW for driving the fatigue test machine and its controller [14].

Fatigue test specimens properties from Nylon 6.6 and cast iron materials is shown in Table 1 [7,15].

Table 1. Properties of Nylon 6.6 plastics and cast iron [7,15].

No.		Properties	Remark
1	**Nylon 6.6**	Density	1.14 g.cm^{-3}
2		Elongation at break	Very good
3		Melting point	250^{o}C
4		Color	White or cream
5		Moisture Regain	4%
6		Ability to protect friction	Excellent
7		Acids	It is not stable with the acidic action
8		Basic	It has enough ability to protect the alkali action
9		Dyes	Direct dyes, acid dyes
1	**Grey cast iron**	Standard	UNS 10004 (SAE G1800)
2		Weight (%)	C=3.4-3.7; Si=2.55, and Mn=0.7
3		Melting point	1300^{o}C
4		Matrix structure	Ferrite (α) and pearlite (Fe_3C)
5		Tensile strength (MPa)	124
6		Uses	Small block cylinder

The results of trials on turning profiles with special tool post of fatigue test specimens from Nylon 6.6 plastic materials is shown in Figure 3 [16].

Figure 3. Special tool post for copy turning specimens profiles [16].

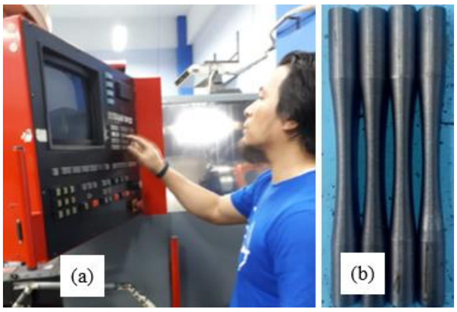

Figure 4. CNC Lathe for turning specimens profiles.

The specimen results from the copy turning device or profile lathe (Figure 3) which show that are very close to their shape and smoothness, which means making fatigue test specimens with a CNC Lathe (Figure 4) can be replaced by simpler profile lathe especially for plastic and soft non-ferro materials.

The trial of profile lathe for turning the PVC, Aluminium, and Brass specimens are shown in Figure 5 [16].

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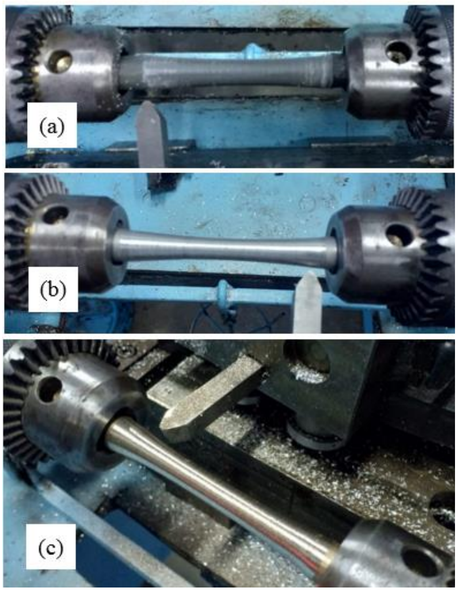

Figure 5. The trial of profile lathe for turning specimens of: (a) PVC, (b) Aluminium, and (c) Brass [16,17].

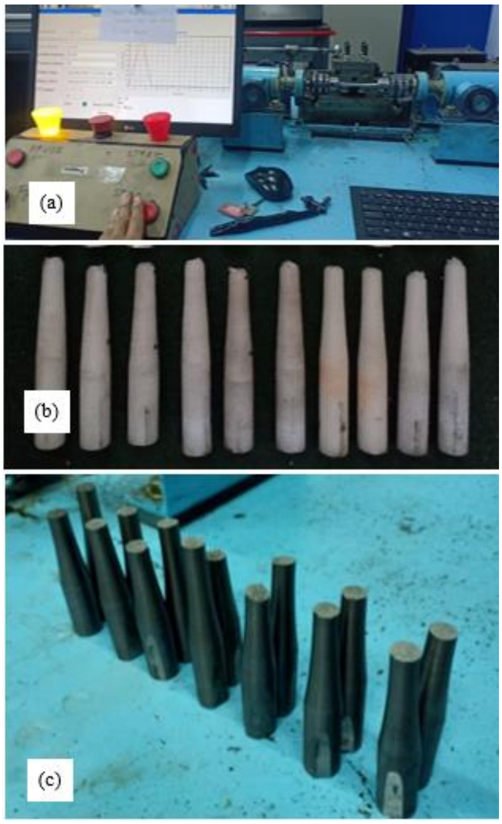

Figure 6. Integrated fatigue test machine prototype (a), Broken Nylon specimens (b), and Broken Cast iron specimens [16].

Fatigue testing for Nylon and Cast iron specimens were succeed conducted by integrated fatigue test machine prototype is shown in Figure 6.

5. Result and discussion

Surface roughness of the specimens as a result of turning with a profile lathe is quite smooth compared to the results of turning with a CNC machine. Refining surface specimens with abrasive paper can produce an equivalent surface roughness.

Profile lathe can be used to turn standard fatigue test specimens for Nylon, PVC, Aluminum and brass.

For specimens made from ferrous metals, and non-ferrous metals which are hard or very resilient, they are not able to be turned with profile lathe, but must be turned by a CNC turning machine.

The fatigue test result for Nylon 6.6 and Cast Iron specimens is shown in Figure 7.

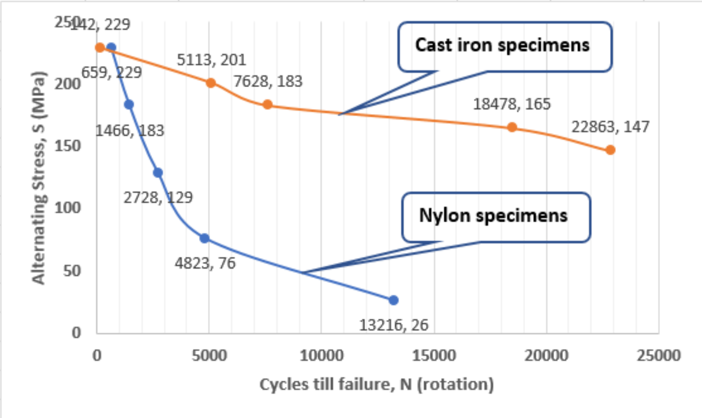

Figure 7. The fatigue test result for Nylon 6.6 and Cast Iron specimens.

The fatigue life of cast iron specimens is higher than that of Nylon. Cast iron material with sloping loading has a longer fatigue life than Nylon, while for Nylon material with a drastically decreasing loading, the fatigue life immediately decreases, which means that Nylon has a shorter fatigue life at a lower loading.

Profile lathe can be used to turn fatigue test specimens with equivalent surface roughness specimens through refinement with abrasive paper.

6. Conclusions and recommendation

From the results of turning some specimen materials by an integrated fatigue test machine with a profile lathe for turning specimens profile and fatigue test of Nylon and cast iron specimens can be summarized as follows:

- Profile lathe can be used to turn fatigue test specimens with equivalent surface roughness specimens through refinement with abrasive paper,
- Profile lathe can be used to turn standard fatigue test specimens for Nylon, PVC, Aluminum and brass, and
- The fatigue life of cast iron specimens is higher than Nylon 6.6, Nylon 6.6 fatigue life ranging from 659 to 13216 rotation at 229 to 26 MPa stresses, and for cast iron from 142 to 22863 rotation at 229 to 147 MPa stresses.

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