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EFFECT OF MATERIAL TYPE AND MINIMUM DIAMETER OF SPECIMENS ON THE FATIGUE LIFE

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Abstract. The obstacle faced during the fatigue test is the waiting time which is quite long and inefficient, especially for test specimens made of ductile metal with waiting times of up to several days. The research method includes reducing the specimen radius to obtain a flexural stress approaching 400 MPa which was originally 229 MPa from a radius of 254 mm to 240 mm with the results of turning the original specimen obtained a minimum diameter of 8.6 mm is reduced to 7.3 mm at a maximum loading of 10 kg. Results of the research are brass specimens C3604BD type with a minimum diameter of 8.6 mm at a flexural stress of 298 MPa showing a fatigue life of 2455546 cycles with a test duration of 1754 minutes and a minimum specimen diameter of 7.3 mm at a flexural stress of 299 MPa showing a fatigue life of 684311 cycles with a test duration of 489 minutes which means that with a minimum specimen diameter of 7.3 mm the fatigue life is 3.59 times shorter than a minimum specimen diameter of 8.6 mm. Meanwhile, for aluminium AA1101 type with a minimum specimen diameter of 7.3 mm at a flexural stress of 182 MPa, the fatigue life is 422117 cycles with a test duration of 278 minutes and with a minimum specimen diameter of 8.6 mm at a flexural stress of 183 MPa, the fatigue life is 389232 cycles with a test duration of 302 minutes which means that with a minimum specimen diameter of 7.3 mm the fatigue life is 1.05 times shorter than the minimum specimen diameter of 8.6 mm or almost the same.

Keywords: fatigue test, rotating bending, C3604BD brass, AA1101 aluminum, copy lathe, specimen profile radius, testing time

1. INTRODUCTION

Research on fatigue life has been carried out on 2 types of specimens, namely brass C3604BD type and AA1101 type with an analysis of the difference in profile radius of standard fatigue test specimens tested on an integrated rotating bending fatigue test machine equipped with a copy lathe on the machine. The reduction of the profile radius on standard fatigue test specimens in order to increase the efficiency of the test time previously there were obstacles that fatigue testing took a long time to several days, especially for materials that were quite ductile such as brass.

Fatigue test of brass specimens with 3 different treatment conditions resulted in fatigue life at flexure strength (S) of 98.95 MPa under normal conditions of 1200000 cycles, at annealing conditions of 380°C worth 800000 cycles, under conditions of making a 1 mm deep groove worth 692000 cycles, and being corroded in solution of NaCl at pH 6.6 and concentration of 38% obtained 1110000 cycles [1]. State of the art of the fatigue properties was reviewed [2] for the corrosion resistance of mechanical components. Fatigue tests on steel alloys increase the fatigue life by 5 to 30%, except for Ti alloys, the fatigue life decreases by 12 to 14%. The difference between fatigue testing using Ultrasonic at 20 kHz reaches a fatigue life of 10^7 cycles for 9 minutes, but with the conventional method at 100 Hz it is achieved for 1 day which results in a drastic reduction in fatigue testing time and costs [3]. The results of the A356 automotive wheel specimen cut at the bottom inner corner of the wheel spokes which were tested for fatigue at S 120 MPa broken at a fatigue life of 380000 cycles showed a decrease in the value of the specimen cut exactly on the inner rim bar, the fatigue test at S 120 MPa broke at fatigue life 360000 cycles [4]. Different treatments on fatigue test specimens resulted in different fatigue life of specimens treated with annealing, giving grooves and corroding can reduce fatigue life than the untreated condition. For specimen material AA of 7075 because it does not show an endurance limit, then in the fatigue test it was stopped at 100 MPa [5]. Fatigue life on the aluminium alloy specimen, AA 6063-TF with a coarse surface obtained fatigue life at 1102472 cycles and on a smooth surface obtained fatigue life at 1281945 cycles which means the fatigue life of a specimen with a smooth surface is 16.3% longer than the fatigue life of specimens with a coarser surface [6]. Fatigue life of specimen AA 2219-T852 as a result of longitudinal forging with a thickness of 8” and 12” shows that the increase in the lowest stress level for sectioned in the longitudinal direction of 12” and short transverse of 8” is lower in fatigue life than short transverse 12” [7]. The average fatigue life of the sectioned AA 1100 specimen in the longitudinal direction of the rolling direction (RD) is 10685087 cycles and for the AA 1050 specimen material is 10171184 cycles. The two values of fatigue life are greater than the fatigue life in the transverse direction of RD which is 8814385 cycles for AA 1100 material and 8596266 cycles for AA 1050 material [8]. The fatigue test specimen material from Aluminium had no fatigue limit, but on steel [9] showed fatigue limit values. The fatigue-tested AA6063 T6 material with a mini-specimen size with an area of 5.5 mm^2 (1.58 mm thickness and 3.5 mm width) sectioned from a complex rectangular profile 45 mm x 45 mm at a maximum stress of 220 MPa resulted in fatigue life at 48011 cycles [10]. The integrated rotating bending fatigue test machine has not only been used in fatigue tests for brass and aluminium but is also used for fatigue tests on cast iron and nylon [11]. The fatigue life of AA 2219-T852 forged longitudinally with a thickness of 12” and a transverse direction of 8” thickness shows an increase from its lowest stress level for a thickness of 12” in the transverse direction [12]. Material AA 6082-T6 was corroded in the salt spray corrosion chamber referring to the ASTM B117 standard. The comparison of all fatigue tests with the same fatigue life was 2 x 10^6 cycles for different S at 98 MPa for 1 month of corrosion, at 91 MPa for 2 months of corrosion, at 68 MPa for 3-month corrosion, and 131 MPa for non-corroded material [13]. AA 6063 with spray coating with sand blasting increased fatigue life from 4182 cycles to 5585 cycles at a load of 9.34 kN, and anodizing with sand blasting increased fatigue life from 3890 cycles to 4200 cycles at a load of 9.34 kN [14]. Specimen AA 7075-T6 which was tested for fatigue at 24 ºC had a lower S-N curve than 160 ºC, both of which were lower than the S-N curve at 20 4oC [15]. The fatigue resistance of aluminium A356-T6 which is cast into sand molds is highly dependent on the presence of casting defects and its microstructural characteristics which in cast results often have porosity and oxides that dominate fatigue performance [16]. Glass polyester composites that were tested for fatigue obtained a fatigue life of 512 cycles at a maximum S of 340 MPa and a fatigue life of 506823 cycles at a minimum S of 140 MPa, while AA2024-T4 obtained a fatigue life of 4783 cycles at a maximum S of 340 MPa and a fatigue life of 16812322 cycles at a minimum S of 140 MPa [17]. The fatigue life of AA2024-T4 is higher than that of Glass polyester composites.

2. METHODS

Fatigue test research was carried out on 2 types of specimens from material C3604BD type and AA1101 type with variable type of material and profile radius of standard fatigue test specimens at a radius of 254 mm and 240 mm as an improvement effort to increase the flexure stress to close to 400 MPa which is desired so that fatigue testing can save shorter test times, which is a problem for ductile metal materials requiring a test time of up to several days for just a single specimen. The fatigue test is carried out on an integrated rotating bending fatigue test machine equipped with a patented copy lathe device. The copy lathe device installed on the integrated rotating bending fatigue testing machine has been submitted for patent registration to the Ministry of Law and Human Rights of the Republic of Indonesia with Number of Application is S00201910197 on November 8, 2019 for claims: the turning can be adjusted at a speed according to the type of specimen material through DC motor and manual actuation of the symmetrical profile lathe tool in a stepwise forward iteration followed by left side movement and then forward movement followed by right side movement until the minimum diameter (final size) of the specimen is achieved.

Fatigue life data is obtained through recording on the computer of the integrated rotating bending fatigue test machine which is equipped with application software that can store operator name, mobile phone number or operator's mobile phone number, the selected loading level, the installed encoder can calculate the amount rotation until the fatigue test specimen breaks when it reaches its fatigue life, the speed that is being applied to the machine is displayed on the monitor screen, and the fatigue test machine can send a short message (sms/short message service) when the machine is started and send sms back when the specimen becomes disconnected or the power source from the electricity source/PLN (state electricity company) is broken. The fatigue testing machine has been equipped with close circuit television (CCTV), so that when the internet network source is still connected, the fatigue testing machine can be monitored remotely online to ensure the specimen has failed or the power source is disconnected. The results of the fatigue life recording can be recorded on the machine monitor screen in the form of the number of revolutions achieved until the specimen breaks and the level of loading applied in kg. The flexure stress is calculated using Formulas (1) to (3).

$$S = M.c/I \tag{1}$$

$$M = (F/2)\,(L/2) \tag{2}$$

$$I = \pi d^4/64 \tag{3}$$

where:
S: Flexure strength (MPa),
M: Flexure moment (Nm),
c: Outer fiber distance or radius of specimen (m),
F: Load (N), in the range of 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 kg.
L: Horizontal distance between bearings load, fixed for the machine is 285 mm,
I: Inertia moment (m^4), and
d: Minimum diameter in the center of of fatigue specimen length (mm).

The concept of fatigue test method R.R. Moore's machine construction and specimen bending illustration is shown in Figure 1.

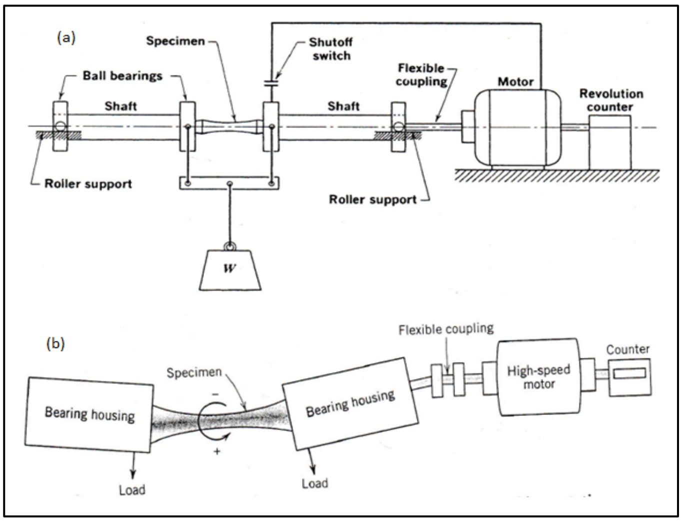

Figure 1. Rotary rod fatigue testing machine by R.R. Moore: (a) Machine construction [18], and (b) Specimen bending [19]

The shape and dimensions of the standard fatigue test specimen with 2 kinds of specimen radii or can also be expressed with a minimum diameter in the middle of the length of the rod are shown in Figure 2.

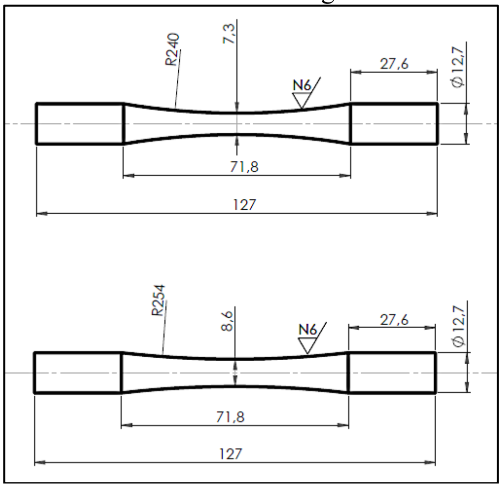

Figure 2. Shape and dimensions of standard fatigue test specimens with 2 kinds of radius on 254 mm and 240 mm

The turning of the brass specimen and the aluminium specimen is shown in Figure 3.

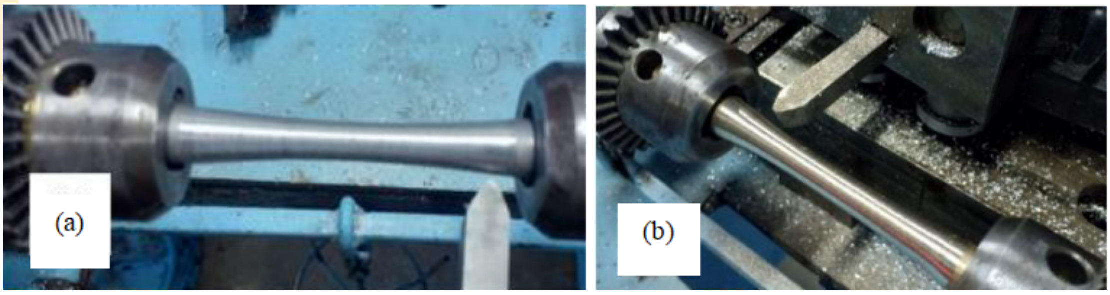

Figure 3. Specimen turning: (a) Brass, and (b) Aluminium

The construction of the integrated rotating bending fatigue test machine front view and rear view are shown in Figure 4.

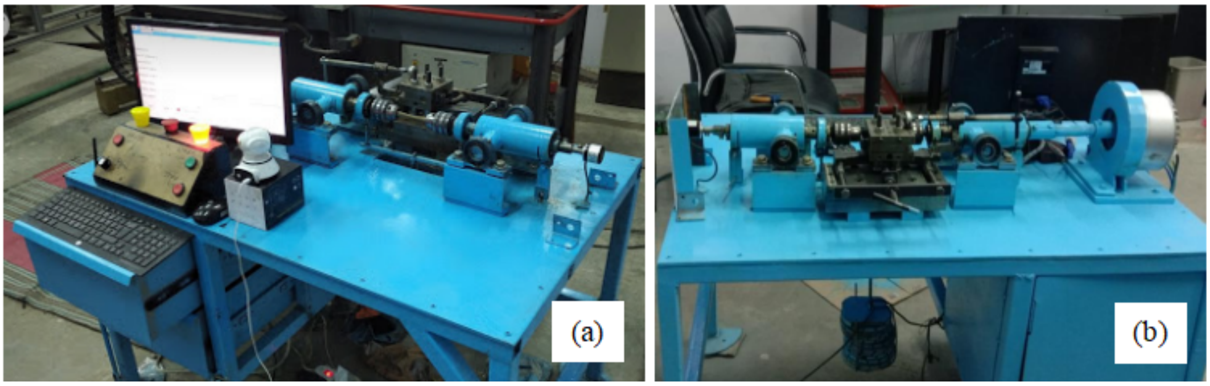

Figure 4. Construction of the integrated rotating bending fatigue test machine: (a) Front view, and (b) Rear view

The brass and aluminium specimens prior to fatigue testing are shown in Figure 5.

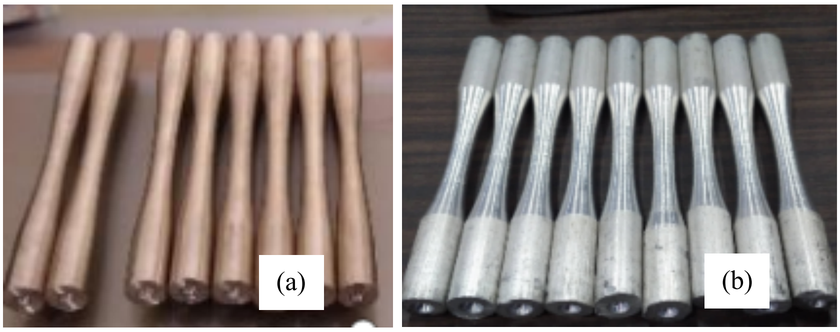

Figure 5. Specimens before fatigue test: (a) Brass and (b) Aluminium

The brass and aluminium specimens after fatigue testing are shown in Figure 6.

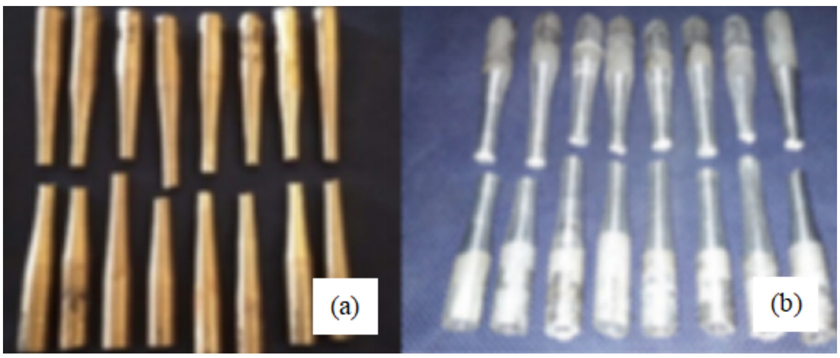

Figure 6. Specimens after fatigue testing: (a) Brass, and (b) Aluminium

The results of fatigue life in the form of the number of rotations of the specimen until it breaks and the flexure stress from the serial data is plotted into an S-N curve which is compared between the data with various test conditions including differences in specimen material and specimen radius profile.

3. RESULTS AND DISCUSSION

The fatigue life of brass C3604BD with different specimen profile radii at 240 mm and 254 mm resulting in a minimum specimen diameter of 7.3 mm and 8.6 mm is shown in Table 1 and Figure 7.

Table 1. Fatigue life of brass C3604BD with minimum specimen diameter of 7.3 mm and 8.6 mm

No.	Brass C3604BD			
	ϕ 7.3 mm		ϕ8.6 mm	
	S (MPa)	N (Cycles)	S (MPa)	N (Cycles)
1	395	201513	298	2455546
2	329	498000	275	2889076
3	299	684311	252	3625736
4	269	1072145	229	4848366
5	240	1783948	201	9385424
6	211	2533160	183	14234556
7	182	4212535	165	18988907
8	153	9731510	147	31322458

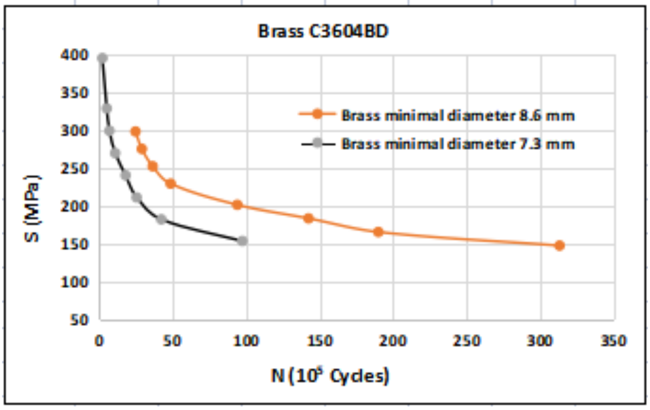

Figure 7. Fatigue life of brass C3604BD minimum specimen diameter of 7.3 mm and 8.6 mm

The fatigue life of AA 1101 with minimum specimen diameter of 7.3 mm and 8.6 mm is shown in Table 2 and Figure 8.

Table 2. Fatigue life of AA 1101 with minimum specimen diameter of 7.3 mm and 8.6 mm

No.	AA 1101					
	ϕ 7.3 mm			ϕ 8.6 mm		
	S (MPa)	N (Cycles)	Duration (minute)	S (MPa)	N (Cycles)	Duration (minute)
1	395	36161	26	229	102444	73
2	329	53553	38	201	174235	124
3	299	65321	47	183	389232	278
4	269	78599	56	165	784704	561
5	240	102651	73	147	1167834	834
6	211	158439	113	129	1960328	1400
7	182	422117	302	111	3841875	2744
8	153	1053240	752	94	8364557	5975

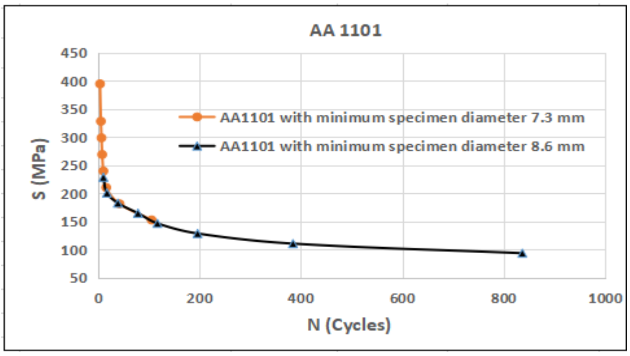

Figure 8. Fatigue life of AA 1101 with minimum specimen diameter of 7.3 mm and 8.6 mm

Brass specimens C3604BD type from the Table 1 with a minimum diameter of 8.6 mm at a flexural stress (S) of 298 MPa showing a fatigue life of 2455546 cycles with a test duration of 1754 minutes and a minimum specimen diameter of 7.3 mm at S of 299 MPa showing a fatigue life of 684311 cycles with a test duration of 489 minutes which means that with a minimum specimen diameter of 7.3 mm the fatigue life is 3.59 times shorter than a minimum specimen diameter of 8.6 mm or save the testing time of 1265 minutes or 21 hours.

Aluminium AA1101 type from the Table 2 with a minimum specimen diameter of 7.3 mm at S of 182 MPa, the fatigue life is 422117 cycles with a test duration of 278 minutes and with a minimum specimen diameter of 8.6 mm at S of 183 MPa, the fatigue life is 389232 cycles with a test duration of 302 minutes which means that with a minimum specimen diameter of 7.3 mm the fatigue life is 1.05 times shorter than the minimum specimen diameter of 8.6 mm or save the testing time 24 minutes what can be said by almost the same.

4. CONCLUSION

Conclusions that can be drawn from the fatigue life research of brass materials C3604BD type and AA1101 type include:

1) The brass specimen type C3604BD with a minimum specimen diameter of 7.3 mm has a fatigue life of 3.59 times shorter than the minimum specimen diameter of 8.6 mm, which means that the testing time is reduced to 1265 minutes or approximately 21 hours, and
2) Aluminium type AA1101 with a minimum specimen diameter of 7.3 mm has a fatigue life of 1.05 times shorter than the minimum specimen diameter of 8.6 mm, which means that the testing time is 24 minutes more efficient or almost the same.

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