Journal of Engineering Science and Technology
Vol. 12, No. 8 (2017) 1999 - 2009

IMPROVEMENT OF FATIGUE STRENGTH OF TIN BABBITT BY REINFORCING WITH NANO ILMENITE

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Abstract

Tin Babbitt is an idle journal bearing material, its fatigue strength limits and its usage. To enhance its fatigue strength, in this paper a Tin Babbitt metal matrix is reinforced with nano Ilmenite. The metal matrix nanocomposite was fabricated by using ultrasonic assisted stir casting technique. ASTM standards in statistical planning for fatigue testing were employed in planning the fatigue tests. Fatigue tests were conducted at three stress levels, i.e., 0.9 UTS, 0.7 UTS and 0.5 UTS. Tests were conducted on a rotating-beam type fatigue testing machine. It was observed that the nano Ilmenite reinforcement enhanced the fatigue strength of Tin Babbitt.

Keywords: Metal matrix nanocomposites, Ultrasonic assisted stir casting, Fatigue strength, Tin Babbitt, Ilmenite.

1. Introduction

Tin Babbitt is design engineer's first choice for using journal bearing material. It possesses all essential properties to be called as an excellent journal bearing material [1]. It is widely used material for meeting low speed, steady load applications. Fatigue strength of the Tin Babbitt limits its usage. Figure 1 shows the comparison of fatigue strengths of the commercially available journal bearing materials. The load bearing capacity of Tin Babbitt is also low about 5-10 MPa [2]. It is very small when compared with other commercially available bearing materials like Al alloys and bronzes [3]. In this paper, it was planned to improve the fatigue strength of the Tin Babbitt by reinforcing it with nanoparticles Ilmenite.

Nomenclatures

Vol.%	Volume percent
Wt.%	Weight percent

Abbreviations

Al	Aluminium
ASTM	American Society for Testing and Materials
MMCs	Metal Matrix Composites
MMNC	Metal Matrix Nanocomposites
SiC	Silicon Carbide
UTS	Ultimate Tensile Strength

($FeTiO_3$) is a medium hard abundantly available ceramic material along the sea cost of many countries. Journal bearing materials usually support rotating steel shafts. So, to avoid the damage to the steel shaft, the medium hard nanoparticle of Ilmenite is used to reinforce the Tin Babbitt matrix.

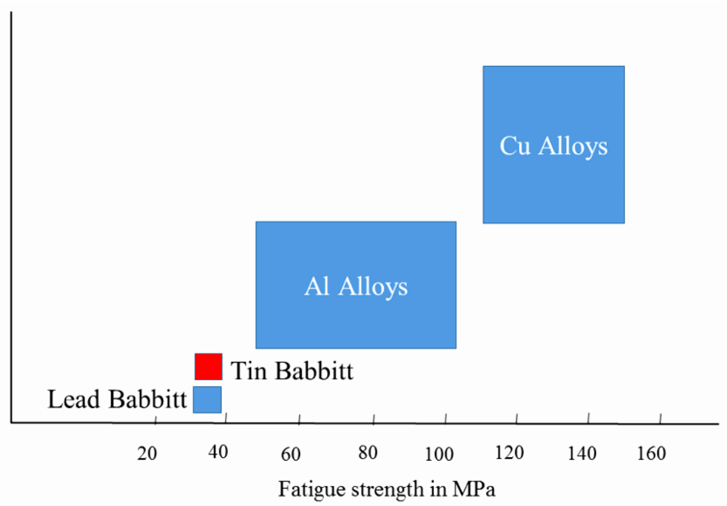

Fig. 1. Comparison of fatigue strengths of the commercial journal bearing materials [4, 5].

Metal matrix nanocomposites (MMNCs) are metal matrix composites (MMCs) with nanoparticle reinforcement. The reinforcement enhances the mechanical behaviour of matrix materials. Many investigators have witnessed the improvement in the behaviour of MMNCs produced by powder metallurgy route [6, 7], high energy ball milling [8], sputtering and stir casting [9-11]. Among all of these methods stir casting is regarded as the most productive and economical. Uniform distribution of nanoparticles and wettability of nanoparticles in metal matrix is a challenge in this process. If the stirring time is increased to achieve uniform distribution, it results in too much gas and oxidation to matrix melt. So, it is necessary to reduce the stirring time to fabricate high-quality composites. Many investigators have developed alternate ways to achieve uniform particle distribution and good wettability [9-14].

Nie et al. [11] have conducted a systematic study for understanding the mechanical behaviour and microstructure of SiC reinforced AZ91 nanocomposite. Authors have successfully used semisolid stirring assisted ultrasonic vibration for processing MMNCs. They observed that increasing stirring time was increasing the viscosity of the melt and making the subsequent ultrasonic treatment less effective, finally attributing to the agglomeration of SiC particles. Murthy et al. [13] have produced Al-fly ash nanocomposite by a combination of vortex method and ultrasonic cavitation. Authors have observed an increase in tensile strength from, compressive strength from 289 MPa – 345 MPa and hardness with the increase of nanoparticles up to 3 % by weight.

Valibeygloo et al. [10] fabricated the Alumina/Al-4.5wt% Cu nanocomposite. The microstructure and mechanical properties were studied at different volume fractions, i.e., 1.5vol.%, 3vol.%, and 5vol.% of Al_2O_3 nanoparticles, fabricated using stir casting method. Calculated amounts of alumina nanoparticles (about φ 50 nm in size) were ball-milled with aluminium powders in a planetary ball milled for 5 h, and then the packets of milled powders were incorporated into the molten matrix. Microstructural studies of the nanocomposites revealed a uniform distribution of alumina nanoparticles in the Al-4.5wt% Cu matrix. Porosity was found in final MMNC, which was just stirrer and nanoparticles added directly. The results indicate an outstanding improvement in compression strength and hardness due to the effect of nanoparticle addition.

Ultrasonic treatment is very effective to reduce gas and oxidation as well as dispersing particles. However, it is very difficult or time-consuming to add particles to melt in the single ultrasonic treatment processing. Besides, the effect of ultrasonic treatment is very micro-localised. Thus, single ultrasonic treatment may be not a good method to fabricate Tin Babbitt MMNC. If mechanical stir is combined with ultrasonic treatment, the disadvantages of both mechanical stir and ultrasonic treatment can be well overcome. Thus, in this work both were combined to use in the fabrication of MMNCs [11]. For a systematic study of the change in the fatigue behaviour, ASTM statistical planning and analysis was used [15].

2. Experimental Details

2.1. Materials

Ilmenite composition was shown in Table 1. The size of particles was 56 nm of uniform shape and size. Babbitt of ASTM B – 23 Grade 2 alloy was used as matrix material. Its composition is shown in Table 2.

Desired Ilmenite/Babbitt nanocomposite was fabricated by using ultrasonic assisted stir casting technique [18]. The temperature – time sequence of this process is shown in Fig. 2. First, Grade 2 Tin Babbitt was melted in steel crucible by heating it to above its liquidus temperature (354 °C) under the protection of Argon gas. Then, it was cooled down to (below 354 °C) the semi-solid condition. Then, preheated (heated to 350 °C) nano-Ilmenite particles of were quickly added to the melt. After semi-solid stirring for required time, the melt was quickly heated to about 400 °C, held for 5 min, and then ultrasonic treatment is given to the melt. During ultrasonic treatment, the tip was dipped about to 15 – 20 mm below the surface and 1000 Watts, 20 Hz ultrasonic vibrations were given to the melt for required amount of time. After ultrasonic treatment, the melt was taken to its pouring temperature i.e. 424 °C, the melt was stirred in the liquid condition at 200 rpm without forming a vortex. Finally, the melt was poured into a preheated cast iron mould (minimum at 121 °C) and allowed for normal solidification.

Table 1. The chemical composition of ilmenite [16].

Element	O	Ti	Fe
Wt.%	47.2	24.99	27.82

Table 2. The chemical composition of ASTM B23 Grade 2 Tin Babbitt [17].

Element	Sb	Pb	Cu	Fe	As	Bi	Zn	Al	Cd	Sn
Wt.%	7-8	0.35	3-4	0.08	0.1	0.08	0.005	0.005	0.05	86-88

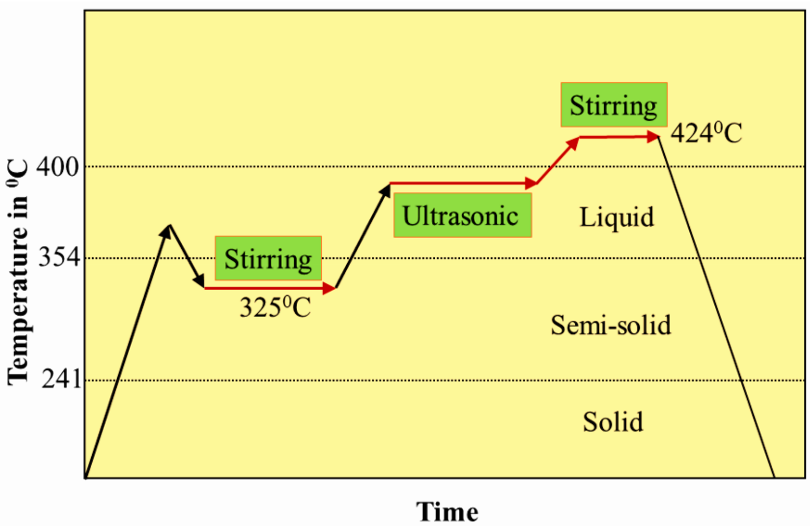

Fig. 2. The temperature – time sequence in fabricating MMNC by ultrasonic assisted stir-casting method.

2.2. Fatigue test

The fatigue strength of materials is often defined as the maximum stress amplitude without failure after a given number of cycles (e.g., 107 or 109). It is estimated that about 90% of service failures of metallic components resulted from fatigue. Fatigue tests are expensive and time-consuming. Little [19] discussed the method for fatigue testing, which includes the design of fatigue experiments, planning of tests and common methods of fatigue data analysis. Lipson and Sheth [20] have discussed the procedure for selection of stress levels, sample size determination and determination of average fatigue life.

The steps in the procedure for statistical planning and conducting fatigue tests as follows [15].

1. Conducting static tests to determine the ultimate tensile strength.

2. Selection of the stress levels based on the result of above tensile test.
3. Determination of sample size.
4. Conducting fatigue tests.
5. Analysing fatigue test results and interpretation of the result.

2.2.1. Conducting tension tests to determine the ultimate tensile strength

The above processing method was used to produce ASTM E8 standard test specimens for both Tin Babbitt, and Ilmenite Reinforced Tin Babbitt MMNC. Tensile tests were conducted on a computerised universal testing machine for 3 test specimens. The average value of ultimate tensile strength (UTS) was taken as the final UTS of the material. The UTS of Tin Babbitt was obtained as 77 MPa and MMNC as 125.6 MPa.

2.2.2. Selection of the stress levels based on the result of above tensile test

Fatigue testing is time-consuming it is recommended to conduct tests at 3 or 5 levels [21]. In this study, it was chosen to conduct tests at three stress levels. The tests were carried out at Level - I (0.9 UTS), Level - II (0.7 UTS), Level - III (0.5 UTS) [19]. Figure 3 shows the standard fatigue test specimen details. Experiments were designed by Statistical design process to find the correct sample size. The relationship between specimens allocated, the permissible variation in the percentage of error, the level of confidence and fatigue life expected variation, is determined as follows.

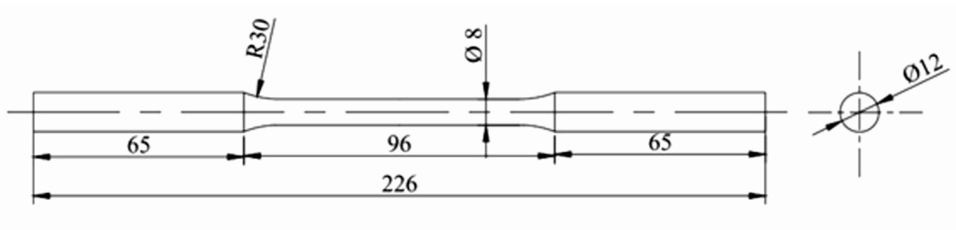

Fig. 3. Dimensions of fatigue test specimen.

A 90% confidence level was used based on the following assumptions for determining the sample size at each stress level.

1) Non-uniform scatters in fatigue lives at all stress levels,
2) 10% percent error is tolerable and
3) The percentage of coefficient of variation (C.O.V) of fatigue lives at the level I, II and III are 4 %, 5% and 7% respectively.

If the variation of fatigue life is more than the assumed at a given stress level, additional specimens need to be tested to bring the variation in percent error and confidence levels within the permissible COV. Table 3 shows the required number of specimens in a sample for 90% Confidence and 10% error for the fabricated MMNC.

Table 3. Required sample size for 90% confidence in fatigue tests for both materials.

Material	Stress (MPa)	Assumed COV (%)	% Error / Assumed COV	Required Sample size
Tin Babbitt	**72 (0.9 UTS)**	4	2.5	3
	56 (0.7 UTS)	5	2	3
	40 (0.5 UTS)	7	1.43	4
Ilmenite/ Tin Babbitt MMNC	**113 (0.9 UTS)**	4	2.5	3
	88 (0.7 UTS)	5	2	3
	63 (0.5 UTS)	7	1.43	4

2.2.3. Determination of sample size.

The number of tests to be conducted at each stress level was determined [20] to be 4, 5 and 7 for stress levels 1, 2, and 3 respectively. The rotating-beam type fatigue testing machine was used for conducting tests. Tests were conducted randomly to minimise the effect of uncontrollable variables. The number of cycles of rotation till the specimen failure was considered as the fatigue life of the specimen. The average speed of rotation was around 1440 rpm.

2.2.4. Conducting fatigue tests

Table 4 shows the fatigue test results used to determine the average fatigue life of the Tin Babbitt according to the initial estimate. Similarly, Table 5 shows the analysis of test results of Ilmenite/ Tin Babbitt MMNC. Table 6 shows the revised Test Plan for both materials. The percentage of actual COV is less than the permissible value. It is clear that three samples are sufficient. However, seven more samples per material were tested. So, a total of 21 specimens shown in Fig. 4 were tested at all the three stress levels to determine the accurate scatter. Fatigue test specimens before and after test are shown in Fig. 5. A large number of specimens are required to be tested at each level, to determine the scatter. Lipson and Sheth [20] given the guidelines for the sample size requirement based on minimum percentage replication as given in Table 7.

Table 4. Analysis of test results used to determine average fatigue life within 10% Error and 90% confidence according to initial estimate for Tin Babbitt.

Sample Number	72 MPa		56 MPa		40 MPa	
	Life (cycles)	Log (Life)	Life (cycles)	Log (Life)	Life (cycles)	Log (Life)
1	126524	5.1022	197259	5.2951	124292	5.0945
2	86524	4.9372	173895	5.2403	276318	5.4415
3	62142	4.7934	98845	4.995	294563	5.4692
					259022	5.4134
AVG	91730	4.9443	156667	5.1768	238549	5.3776
Standard Deviation	-	0.1546	-	0.1599	-	0.175
% C. O. V	-	3.13	-	3.09	-	3.26
Permissible % C. O. V	-	4	-	5	-	7

Table 5. Analysis of test results used to determine average fatigue life within 10% Error and 90% confidence according to initial estimate for MMNC.

Sample Number	113 MPa		88 MPa		63 MPa	
	Life (cycles)	Log (Life)	Life (cycles)	Log (Life)	Life (cycles)	Log (Life)
1	159799	5.2036	194602	5.2892	252651	5.4026
2	110691	5.0442	95410	4.9796	353893	5.5489
3	69122	4.8397	239133	5.3787	408443	5.6112
	-	-	-	-	109134	5.038
AVG	113204	5.0292	176382	5.2159	281031	5.4488
Standard Deviation		0.1825		0.2095		0.2568
% C. O. V		3.63		4.02		4.72
Permissible % C. O. V		4		5		7

Table 6. Revised test plan for both materials.

Material	Stress (MPa)	Actual % C.O. V	% Error / Actual C.O.V (%)	Actual Sample size
Tin Babbitt	72	3.13	3.03	7
	56	3.09	3.23	7
	40	3.26	3.06	7
Ilmenite/ Tin Babbitt MMNC	113	3.63	2.76	7
	88	4.02	2.49	7
	63	4.72	2.12	7

Table 7. Replication and sample size in fatigue life testing [20].

Type of Test	Minimum Percent Replication	Minimum Number of Specimens
Preliminary and Exploratory	17 – 33	06 – 12
Research and Development Testing	33 – 50	06 – 12
Design Allowances Data	50 – 75	12 – 24
Reliability Data	75 – 88	12 – 24

Percentage replication is the portion of a total number of specimens that may be used for obtaining an estimate of the variability of replicate tests. The percentage replication was calculated as [15]:

Percentage Replication=100 [1 - (SL/N)]

where

SL = Total number of different stress levels used in testing = 3

N = Total number of specimens tested = 3 stress levels x 7 specimens = 21

Replication percentage = [1-(3/21)]×100

= 85.72 % that agrees with the values given in Table 7.

Table 8 shows the results of revised sample size = 7, for each type of material under testing.

Fig. 4. Fatigue test specimens before testing.

Fig. 5. Fatigue test specimen before and after the test.

Table 8. Results of seven fatigue tests conducted of Tin Babbitt.

Sample Number	72 MPa		56 MPa		40 MPa	
	Life (cycles)	Log (Life)	Life (cycles)	Log (Life)	Life (cycles)	Log (Life)
1	72736	4.8618	254059	5.405	391486	5.5928
2	184597	5.2663	98051	4.9915	131260	5.1182
3	81912	4.9134	197068	5.2947	238596	5.3777
4	67292	4.828	90871	4.9585	298047	5.4743
5	97088	4.9872	192864	5.2853	214179	5.3308
6	146968	5.1673	191327	5.2818	126747	5.103
7	44653	4.6499	104393	5.0187	302663	5.481
AVG	99321	4.9535	161234	5.1765	243283	5.354

2.2.5. Analyzing fatigue test results and presentation of data

The following Table 9 shows the results of the fatigue tests conducted on the revised sample size 7 for Ilmenite/ Tin Babbitt MMNC.

Figure 6 shows S-N curves for both Tin Babbitt and Ilmenite/Tin Babbitt MMNC. The fatigue strength of MMNC is superior to that of the matrix alloy. From Fig. 6 it is confirmed that the fatigue strength of Ilmenite/ Tin Babbitt MMNC has been improved due to nano size particle reinforcement. The fatigue strength of the material was increased from about 35 MPa for 2,50,000 cycles of operation to about 60 MPa for 2,80,000 cycles of operation.

Table 9. Results of fatigue failure of revised sample size of 7 for Ilmenite/ Tin Babbitt MMNC.

Sample Number	113 MPa		88 MPa		63 MPa	
	Life (cycles)	Log (Life)	Life (cycles)	Log (Life)	Life (cycles)	Log (Life)
1	106748	5.0284	205165	5.3122	310176	5.4917
2	168653	5.227	188378	5.2751	260424	5.4157
3	153572	5.1864	173544	5.2395	374163	5.5731
4	73367	4.8656	197841	5.2964	161740	5.2089
5	123551	5.0919	97332	4.9883	383919	5.5843
6	135979	5.1335	145222	5.1621	290430	5.4631
7	75749	4.8794	208887	5.32	173545	5.2395
AVG	119660	5.0589	173767	5.2277	279200	5.4252

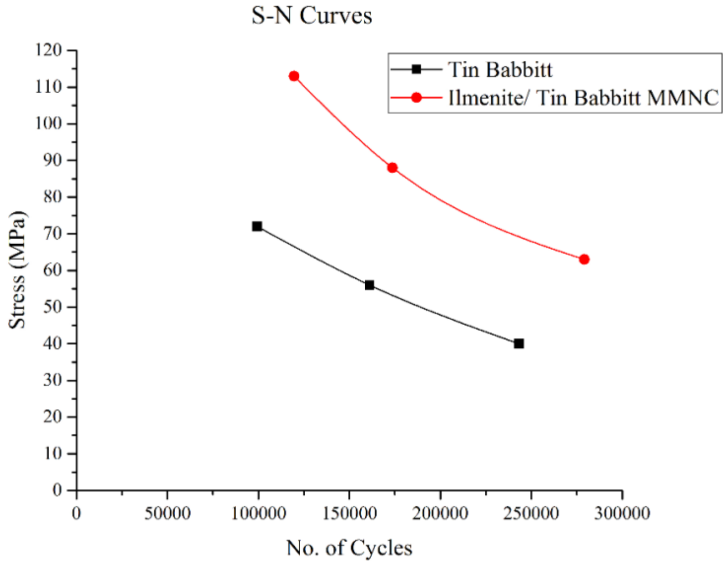

Fig. 6. Comparison of fatigue behaviour of Tin Babbitt and Ilmenite/ Tin Babbitt MMNC.

2.3. Microstructure

To find the reason for improment in fatigue strength, microscopic images were studied. Samples were prepared for light microscopic investigation from the MMNC. Specimens were cut from the centre of the composites. Specimens were etched with 2ml HNO_3 added to 98ml Ethanol of 95% pure and immersed for 75 seconds [22]. As seen the microscopic image is shown in Fig. 7. Big dark areas are the Cu_6Sn_5 intermetallics are distributed in the tin matrix. Tiny black spots are the uniformly distributed nano reinforcement in Tin. In the below microstructure, it can be observed both Cu_6Sn_5 and nano reinforcement both are uniformly distributed in the matrix. Both stir casting and ultrasonic treatment together play a significant role in achieving it.

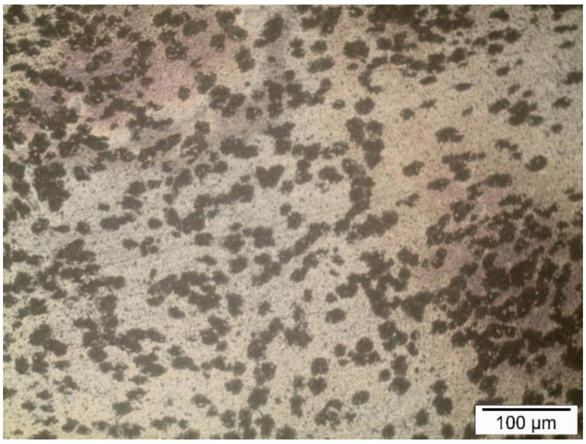

Fig. 7. Microstructure of fabricated Ilmenite/ Tin Babbitt MMNC.

3. Conclusions

An experimental study was conducted to study the effect of the nano Ilmenite reinforcement on the fatigue strength of the Tin Babbitt. MMNC was fabricated by using the ultrasonic assisted stir casting technique. Experiments were conducted to plot S – N curves for Tin Babbitt and Ilmenite/ Tin Babbitt MMNCs. Their fatigue strengths were compared and it was observed that the nano reinforcement has enhanced the fatigue strength of the Tin Babbitt from 35 MPa to 60 MPa.

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