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FATIGUE BEHAVIOUR OF Al-Si ALLOYS SUBJECTED TO REVERSED BENDING

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ABSTRACT

Most of the machine components are subjected to fatigue failure during their operation. Fatigue failure is a damaging process of components under cyclic loading. The purpose of the present work is to investigate the fatigue behavior of eutectic Al-Si cast alloys with the alloying elements of Cu, Mg and Ti. Standard specimens of rotating beam machine are prepared by machining process and tested on fatigue machine under completely reversed bending. The specimens are tested under constant bending moment and constant speed. The life cycles and bending stresses for various specimens are calculated by varying the composition of aluminum experimentally. The results indicate that the addition of Cu, Mg, Ti and grain refiner to the eutectic Al-Si cast alloy increases the life cycle of the alloy under constant load and speed.

Keywords: *Fatigue, eutectic Al-Si cast alloys and life cycles.*

1. Introduction

Structural materials, machine components and materials utilized in many industrial and specialized fields such as aerospace, automobile, defense, power generation among others are frequently subjected to varied stress cycles or dynamic loading conditions during the course of their use. It is thus not surprising that most of these materials fail primarily by fatigue whilst in service. Fatigue failures are reported to account for more than 75% of renowned materials failures of which a great percent occur catastrophically.

The development of aluminum silicon alloys is very important due to their high strength to weight ratio, high wear resistance, low coefficient of thermal expansion, high thermal conductivity, high corrosion resistance, good cast performance, good weldability etc which makes them attractive candidate material in many fatigue and tribological applications, aerospace and other engineering sectors where they can successfully replace ferrous components in many applications. For this purpose many researches had been done to enhance their fatigue and wear properties. Al-Si alloys are mainly used in cast form in important components like pistons, engine blocks, cylinder liners, rocker arms, air conditioner compressors, brake drums etc. The improvement in the fatigue and mechanical properties depends on number of material related properties like shape, size and size distribution of the second phase particles in the matrix and microstructures. With the development of automobile industry, the need of eutectic Al-Si alloys increasing greatly. Al-Si alloys containing 7 to 12 wt% silicon are known as eutectic Al-Si alloys.

Aluminum silicon alloys can be strengthened by adding small amount of Cu, Ni or Mg and the presence of silicon provides good casting properties. Copper results in the precipitation of $CuAl_2$ particles in the structure. A number of studies have been reported on the fatigue behavior of Al-Si alloy materials. It has been estimated that at least 75% of all machine and structural failures have been caused by some form of fatigue (Richard G. Budynas, 1998). Fatigue failures occur most often in moving machinery parts such as shafts, axles, connecting rods, valves and springs. Mattos et al [1] reported that the fracture surface of fatigue test specimens, a clear contrast between the micro mechanism of fatigue zone (striations) and the final fracture zone (dimples), and fatigue crack initiation occurs at the porosities near the surface. Gholami et al [2] reported that the fatigue strength of the ultrafine-grained is higher than the fatigue strength of the coarse- grained CuNiSi alloys. S.Jana [3]

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studied on the effect of stress ratio on the fatigue behavior of a friction stir processed cast AlSiMg alloys. Cevdet Kaynak and Suha Boylu [4] reported that, SiC particulates improved fatigue resistance mainly by acting as barriers to cracks and/or deflecting the growth plane of cracks resulting in decreased crack propagation rates. Gonzalo et al[5]studied on the fatigue endurance and rack propagation under rotating bending fatigue tests on aluminium alloys. Jiang Xiao-song et al [6] studied about Microstructure-based analysis of fatigue behavior of Al-Si-Mg alloy and reported that the dislocation structure of Al-Si-Mg alloy is dependent on stress amplitude. M. Harun et al [7] has investigated the effects of element additions on the wear of Al-Si alloys. M. S.A.Kori and M.S.Prabhudev [8] investigated on the wear rate of hypoeutectic Al-Si alloys with minor additions of copper at elevated temperatures and concluded that wear rate increases with the normal pressures, sliding speeds and sliding distances at a constant temperature of 300^{0}C. Elmadagli et al [9] reported that the addition of 0.02 wt% strontium m to the Al-7 wt% Si alloy increases the wear resistance. A.S.Anasyida et al [10] has investigated the effect of cerium addition to the Al-Si alloys and found that increasing the cerium content up to 2% wt. increases the wear resistance of the alloys and then decreases. Shivanath et al [11] investigated the sliding wear behavior of aluminum silicon alloys reported that wear resistance is good for the hypereutectic aluminum silicon alloys. D.K.Dwivedi [12] reported that the addition of alloying element to the Al-Si alloy not only reduces the wear rate but also increases the transition load. K.G.Basava Kumar et al [13] investigated on the wear resistance of hypoeutectic Al-Si alloys using copper and reported that grain refined and modified cast alloys work hardened to a greater extent than the untreated alloys. Ibrahim.S [14] investigated the wear behavior of aluminum silicon alloys under different velocities and temperatures by adding small amount of copper. Sivarajan and Padmanabhan [15] concluded that TiAlN coatings can be an excellent choice to modify friction behavior and improve wear resistance of tool material. Sono Bhardawaj [16] reported that the adhesive wear is decreased remarkably due to increasing percentage of graphite powder.

The present work investigates the influence of alloying elements and the grain refiner on the life cycle of Al-Si alloy on rotating beam fatigue testing machine under a constant bending moment and constant speed. Table 1 indicates the details of the alloy compositions.

Table 1 Test specimens of cast alloys

Sl. No	Alloy designation	Percentage of elements in the alloy				
		Al	**Si**	**Cu**	**Mg**	**M51**
1	P-1	90	10	-	-	-
2	P-2	87.5	10	2.5	-	-
3	P-3	87	10	2.5	0.5	-
4	P-4	86	10	2.5	0.5	1

2. Experimental Procedure

In the present investigation four different eutectic cast alloys were prepared. P-1 alloy was the unmodified one. P-2 alloy contains small amount of Copper. Alloy P-4 was grain refined with Al-5Ti-1B (M51). Green sand is used for the preparation of mould. A typical mixture by volume could be 89% silica sand, 4% water and 7% clay is used. Single piece wooden block pattern of diameter 25mm and length 400mm is prepared for the mould. The cavity was prepared by taking the long hollow cylindrical shell of 100 mm diameter and 300 mm length. The wooden patterns are placed in the middle of the hollow cylindrical shell and the prepared green sand is filled in to the shell in the form of layers. After the sand was filled to the top of the shell, the pattern was removed carefully without any disturbance to the prepared hollow cavities as shown in Fig. 1

Fig.1 Hollow cavities

Fig. 2 Al-Si alloy specimen in the crucible.

The specimen in the crucible furnace is shown in Fig. 2. The rotating beam fatigue testing machine involves the preparation of carefully polished test specimens (surface flaws are stress concentrators) which are cycled to failure at stress levels. The test specimens are to be machined from test samples with the aid of specially sharp cutting tools to avoid any other additional deformation or over heating during machining. The specimens are ground on precision machine and finally polished in longitudinal direction of the specimen with the finest grade of emery. During machining care must be taken to avoid undercuts at the transition of fillets and cylindrical section. The test specimen must be greased with non-corroding grease to protect against undesirable corrosion. The fatigue test specimens are made as per the DIN 50113 standards. The Fig. 3 shows the schematic diagram of the fatigue test specimen.

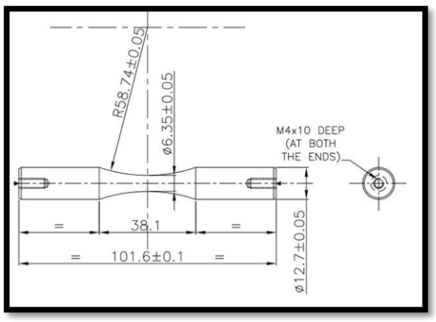

Fig. 3 Dimensions of the test specimen

The photograph of the machined test specimen of the fatigue rotating beam machine is shown in Fig. 4.

Fig. 4 Test specimen

A fatigue rotating beam testing machine was used to determine the life cycle of aluminum silicon alloys. The rotating beam fatigue machine is used to elucidate the mechanical behavior of materials and machine parts subjected to stresses, which continuously or repeatedly alternate about a mean value of zero between positive and negative values of equal magnitude. The test specimen is rotated by means of an AC motor. The specimen is supported on one end and load is applied at the other end by means of loading lever arrangement. The test duration and no of cycles are displayed on front panel, motor stops when specimen fractures during test. The speed of motor is varied by an AC drive. Spindle is mounted on double row taper roller bearings in the front, on one end of spindle a taper to seat collet and other end is connected to motor shaft through a coupling. Spindle is housed in a housing and firmly clamped on to base plate, the specimen for test is clamped on collet and rotated by motor. One end of specimen is clamped on collet and firmly rotate with it, the other end of specimen is subjected to normal load by suspending a holder on the outer diameter. The specimen rotate inside the holder on bearing and is pulled down to apply load by loading lever. A load cell is connected between the specimen holder and loading lever to measure applied radial load. A part catcher is fixed below the bearing support to collect specimen after fracture. The machine operation is controlled by an electronic controller and is placed near the machine at a convenient position for operation. The controller is connected to machine through control cable and signal input cable. For easy operation of machine all switches are mounted on the front panel of controller. the front panel of controller has four displays namely, normal load, counter, speed and timer. The potentiometer knob is used for setting the speed of the specimen in rpm. A toggle switch is used for selecting mode of test duration either in time or rev mode. The fatigue rotating beam testing machine (DUCOM) and controller are shown in Fig. 5 and Fig 6 respectively.

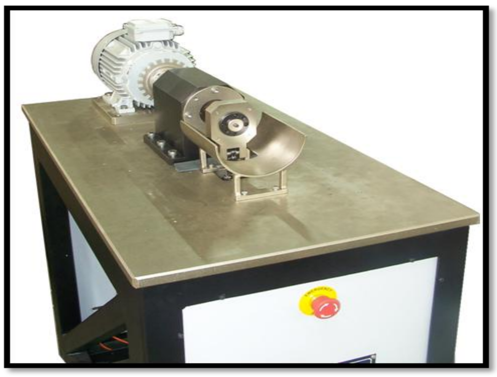

Fig. 5 Fatigue testing machine

Fig. 6 Controller of the fatigue machine

3. Results and Discussion

The fatigue behavior of Al-Si cast alloys depends on the size, shape of the silicon particles and size distribution of the α-Al grains in the interdendritic region. The test was conducted at a constant bending moment and constant speed.

A fatigue rotating beam testing machine is used to determine the life cycle of aluminum silicon alloys. When the specimen is rotated about the longitudinal axis, the upper and the lower parts of the specimen gauge length are subjected to tensile and compressive stresses respectively. Therefore, stress varies sinusoidally at any point on the specimen surface. The test proceeds until specimen failure takes place. The number of cycles survived by the test specimen at constant bending moment and speed are counted when specimen fractures during test. Table 2 indicates the life cycles of the test specimens P-1, P-2, P-3 and P-4 at constant load and speed under complete reversed bending before fracture occurs. It is observed that the life cycle of the test specimen P-4 is more than the unmodified test specimens P-1, P-2 and P-3 due to the grain refinement of aluminum particles.

Table 2 Life cycles of test specimens

S. No	Alloy designation	Load (N)	Speed (rpm)	Life (rev)
1	P-1	125.077	1500	2,38,175
2	P-2	125.077	1500	2,90,378
3	P-3	125.077	1500	3,15,008
4	P-4	125.077	1500	3,73,855

S-N diagrams for different R-ratio's are plotted using ANSYS software by taking alternating stress in ordinate and cycles in abscissa on log-log graph sheet using ANSYS simulation software. Figures 7 to 10 shows the relationship between the number of cycles (N) for fracture and the maximum value of the applied cyclic stress for different R ratios of -1, -0.5, 0 and 0.5.

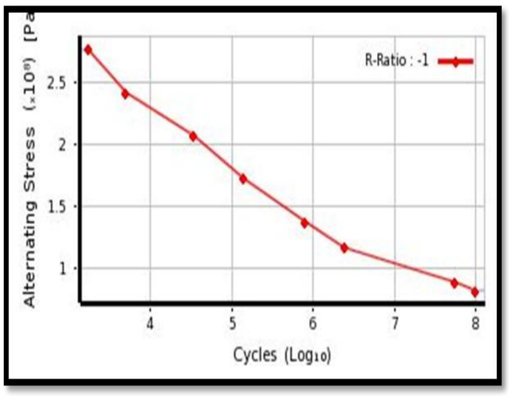

Fig.7 S-N diagram for R-ratio -1

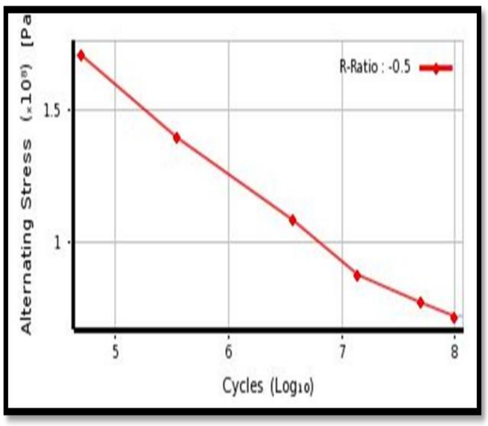

Fig. 8 S-N diagram for R-ratio -0.5

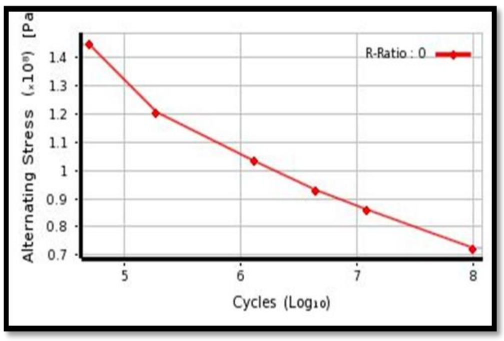

Fig. 9 S-N diagram for R-ratio 0

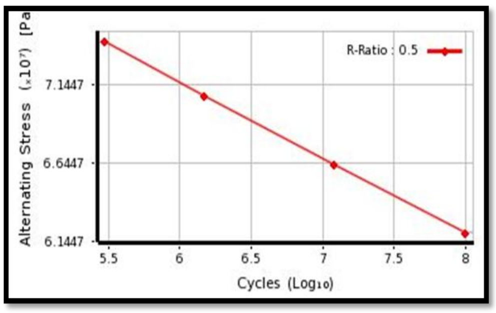

Fig. 10 S-N diagram for R-ratio 0.5

The stresses induced for the Al-Si alloys is calculated as follows.

Applied weight (m) =2.550 kg
Speed (N) = 1500 rpm
Diameter of neck (D) = 6.35 mm
Length (L) = 50 mm
Mechanical advantage = 5
Load on the specimen = m x g x (M.A)
= 2.550 x 9.81 x 5
= 125.077N
Bending Moment (M) = Load x Length
= 125.077 x 50
= 6253.875 N-mm.
Moment of Inertia (I) = $(\pi/64)$ x D^4
= $(\pi/64)$ x 6.35^4
= 79.81 mm^4
Distance from N.A to top fiber (Y) = D/2
= 3.175mm

Bending stress induced (S) = (M x Y) / I

=248.79 MPa

The stress induced in the Al-Si alloys from the experimentation is lying between the minimum value (1.0519 MPa) and maximum value (286.48 MPa) obtained from the ANSYS simulation software. Further, the life cycles survived in the Al-Si alloys from the experimentation are lying between the minimum value ($1.0484x10^5$) and maximum value ($1x10^8$) obtained from the ANSYS simulation software.

4. Conclusions

The influence of alloying elements and the grain refiner on the life cycle of Al-Si alloy using rotating beam fatigue testing machine under a constant bending moment and constant speed was investigated and the following conclusions were drawn.

- The life cycle of the Al-Si cast alloy depends on the alloying elements added to the unmodified alloy.
- It is observed that the life cycle of the grain refined Al-Si alloys is more when compared to the other unmodified alloys.
- It is observed that the life cycles of the Al-Si alloys obtained using experimentation are lying within the minimum and maximum limits calculated using ANSYS simulation software.
- It is observed that the bending stress induced in the Al-Si alloys using experimentation is lying within the minimum and maximum limits calculated using ANSYS simulation software.

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Nomenclature

Symbol	Meaning	Unit
N	Speed	rpm
M	Bending Moment	N-mm
I	Moment of Inertial	mm^4
S	Bending stress	MPa