CHAPTER 4

TESTING OF MECHANICAL PROPERTIES

In general, industries may need a perfect knowledge of finding the mechanical and corrosion properties of various engineering materials for the design and operation of mechanical components working under various loads, speeds, and also at high temperatures. The engine bearing is an important component used in I.C. Engines and also various stresses are imposed on the bearing due to various moving parts like crankshaft, connecting rod, tappets and cam shaft. The development of this bearing material is closely linked with engine development. Therefore the design and selection of bearing material is necessary in an optimized manner and their properties directly depend upon the properties of the material. This section is concerned with the testing of various mechanical properties such as hardness, tensile, flexural, izod impact, and fatigue testing and the discussion of their results.

4.1 HARDNESS TEST

Hardness is resistance of material to plastic deformation caused by indentation or it refers to resistance of material to scratching or abrasion. Hardness may be measured from a small sample of material without destroying it. Principle of any hardness test method is forcing an indenter into the sample surface followed by measuring dimensions of the indentation (depth or actual surface area of the indentation). Hardness is not a fundamental property and its value depends on the combination of yield strength, tensile strength and modulus of elasticity. The benefits of hardness test are easy, inexpensive, quick, non-destructive, and may be applied to the
samples of various dimensions and shapes. Hardness testing is performed by using Brinell hardness tester RAB-250 as shown in Figure 4.1.

Figure 4.1 Brinell hardness testing machine

The indentation has conducted with a 5 mm ball indenter at a load of 2500 N. The load application time is 30 seconds. The diameter of the indentation left in the specimen shown in Figure 4.2, is measured by using low powered microscope. The diameter of the impression has been taken as normally the average of three readings at different locations, which helps to determine the mean values of the hardness.
The Brinell Hardness Number (BHN) is calculated by dividing the load applied by the surface area of indentation as given in Equation (4.1).

\[
BHN = \frac{2F}{\pi D \sqrt{D - (D^2 - D_i^2)}}
\]  

(4.1)

4.2 TENSILE TEST

Mechanical properties which are important in the design engineer’s point of view, but it differ from that of a manufacturing engineer. In design, mechanical properties such as elastic modulus and yield strength are important in order to resist permanent deformation under applied stresses. Thus, the focus is on the elastic properties. In manufacturing, the goal is to apply stresses that exceed the yield strength of the material so as to deform it to the required shape. Thus, the focus is on the plastic properties. The tensile test is one of the most widely used methods to determine the mechanical properties of materials. The typical Universal Testing Machine (UTM) is used to conduct the tensile test is shown in Figure 4.3.

While applying an axial force to a specimen starts to elongate from its original length (l0), resulting in the reduction of cross-sectional area from...
Ao to A until a fracture occurs. The load and change in length between two fixed points (gauge length) of the test sample is recorded until it fractures. By using the instantaneous length, applied load and cross-sectional area, the true stress and true strain values are calculated and these help to construct the stress-strain curve. From this curve, the elastic modulus and yield strength are determined. The highest load in the tensile test gives the Tensile or Ultimate Tensile Strength (UTS).

Figure 4.3 Universal testing machine (UTM)

After fracture, the final length and cross-sectional area of the specimen is used to calculate the percentage elongation and percent reduction in area, respectively. These quantities show the ductility of the material. Three specimens from the same material are made to determine the mean value of Tensile Strength. The typical standard specimen used for the tensile test is shown in Figure 4.4.
The strength of a material is measured in terms of either the stress necessary to cause appreciable plastic deformation or the maximum stress that the material can withstand. In engineering design, the measure of materials ductility is also important, which is used to measure how much it can be deformed before it fractures. Ductility is directly incorporated in design and it is included in material specifications to ensure quality and toughness. Low ductility in a tensile test often is accompanied by low resistance to fracture under other forms of loading. The other important property is elastic property which is also obtained during tensile testing. The stress and strain curves are plotted based on the tensile measurements and theoretical calculations.

### 4.2.1 Theoretical Calculation of Tensile Test

The engineering stress ($\sigma_e$) at any point is defined as the ratio of the instantaneous load or force ($F$) and the original area ($A_0$).

$$\text{Stress, } \sigma_e = \frac{F}{A_0} \quad (4.2)$$

The engineering strain ($\varepsilon$) is defined as the ratio of the change in length ($L - L_0$) and the original length ($L_0$).
During elastic deformation, the engineering stress-strain relationship follows the Hook’s law and the slope of the curve indicates the Young’s Modulus (E) which is given by

\[
E = \frac{\sigma_e}{e}
\]  

(4.4)

The tensile loading continues beyond the elastic portion, and yielding occurs at the beginning of plastic deformation. The yield stress can be obtained by dividing the load at yielding (P_y) by the original cross-sectional area of the specimen as given by

\[
\text{Yield stress, } \sigma_y = \frac{P_y}{A_0}
\]  

(4.5)

Aluminium material having an FCC crystal structure does not show the definite yield point in comparison to those of the BCC structure materials like iron and steel. Therefore the yield strength has to be calculated from the load at 0.2% strain divided by the original cross-sectional area which is given as

\[
\text{Yield stress, } \sigma_{0.2\%y} = \frac{P_{0.2\%y}}{A_0}
\]  

(4.6)

As the load increases, the specimen continues to undergo plastic deformation and at a certain value its cross-section reduces due to the form of necking. At that point the stress reaches the maximum value, which is called Ultimate Tensile Strength (UTS) and it is given as
Ultimate Tensile Strength, \[ UTS = \frac{F_{\text{max}}}{A_0} \] (4.7)

Ductility can be defined as the amount of deformation or strain that the material can withstand before failure. For metal forming processes, increasing the ductility increases the material formability. In general, the ductility of the specimen is defined in terms of elongation (EL) or the area reduction (AR) before fracture, and the relations are given below

\[ \text{Elongation, } EL = \frac{(L_m - L_0)}{L_0} \] (4.8)

\[ \text{Reduction in area, } AR = \frac{(A_0 - A_{\text{min}})}{A_0} \] (4.9)

### 4.3 IZOD IMPACT TEST

The specimen is subjected to load continuously and slowly in both tensile and hardness testing and there is no sudden impact load applied. The reaction of material measured through a sudden tension due to a quick blow or impact load, by means of an impact tester. Toughness is a measure of material’s ability to withstand sudden or impact loads. It is important in the engineering point of view. The measure of ability of material is to withstand an impact load without fracture. Two standardized tests, the Charpy and Izod, are commonly used to measure impact energy and the primary differences between these two techniques lie in the manner of the specimen supported.

Impact test is performed by using impact tester machine DT-30 which is shown in Figure 4.5. The test specimen is clamped upright in an anvil, with a v-notch at the level of the top of the clamp. The specimen is hit by a striker carried on a pendulum which is allowed to fall freely from a fixed
height. If breakage does not occur, a heavier hammer is used until failure occurs. After fracturing the test piece, the height to which the pendulum rises is recorded by a slave friction pointer mounted on the dial, from which the absorbed amount of energy is read. The mean value of the impact strength is determined by taking five readings from the five different specimens of the same material.

Figure 4.5 Impact testing machine

The notched type of specimen is prepared according to ASTM standard D256, which helps to determine the impact resistance. The typical standard specimen used for the impact test is shown in Figure 4.6.
4.3.1 Theoretical Calculation of Pendulum Test

\[ W_a = mg \alpha \]  
\[ E_i = mga = Wa \]  \hspace{1cm} (4.10)

Figure 4.7 Typical pendulum machine

The typical pendulum machine used to calculate the impact strength is shown in Figure 4.7. The mass of the hammer (m) is raised to a height at a distance of ‘a’. Before the mass (m) is released, the potential energy will be

Initial energy, \( E_i = mga = Wa \)  \hspace{1cm} (4.10)
Impact velocity, \( v = \sqrt{2ga} \)  \hfill (4.11)

After striking the specimen at a height of ‘b’, the energies will be

Energy after rupture, \( E_r = mgb = Wb \)  \hfill (4.12)

Energy absorbed during impact, \( E_{abs} = E_i - E_r = mg(a-b) \)  \hfill (4.13)

### 4.4 FLEXURAL TEST

Increasing demand of high quality and reliable materials for engine bearing applications, flexural tests have become essential in both research development and manufacturing process. These tests helped to define a material’s ability to resist deformation under load. The flexural strength of the material gives critical insight into the modulus of elasticity in bending, flexural stress and flexural strain.

![Flexural testing machine](image-url)

**Figure 4.8 Flexural testing machine**
The purpose of this test is used to measure the flexural strength of material or alloy by use of a simple beam with three-point loading. The specimen is positioned on a support span, and the load is applied to the centre. Hence the maximum moment occurs at the midpoint. The typical flexural testing machine used in this work is shown in Figure 4.8.

The flexure strength is also known as modulus of rupture. The various parameters considered in this test are support span, speed of loading, and maximum deflection. The thickness of the specimen is selected based on the standards of ASTM D790 and the typical specimen used in this test is shown in Figure 4.9. The loading test shall be performed until the specimen fractures and measurements shall be made and recorded continuously or at regular intervals. The loading rate shall be adjusted so that the strain rate in the test portion is approximately 1-2% per minute. The tests are conducted at room temperature and a minimum of three tests are conducted and the average value has been taken.

![Figure 4.9 Flexural test specimen (ASTM D790)](image)

### 4.4.1 Theoretical Calculation of Flexural Test

The flexural strength of the specimen is calculated by the following relations by neglecting the weight of the beam.
Flexural tensile strength, \( R = 1.5 \left( \frac{PL}{bd^2} \right) \) (4.14)

If the fracture is initiated on the tension surface within the middle third of the span length, the modulus of rupture can be calculated using the following relations

Flexural tensile strength, \( R = 1.05 \left( \frac{PL}{bd^2} \right) \) (4.15)

If the fracture occurs on the tension surface outside the middle third of the span length by not more than 5% of the span length, the modulus of rupture can be calculated using the following relations

Flexural tensile strength, \( R = 3.15 \left( \frac{Pa}{bd^2} \right) \) (4.16)

4.5 FATIGUE TEST

Material cracks or failures because of repeated (cyclic) stresses applied below the ultimate strength of the material and is known as fatigue. Failure caused by cyclic loading is termed as fatigue and the number of total loading cycles applied until fracture is called fatigue-life. This failure frequently occurs quite suddenly with a catastrophic result. Most of the machinery and several structures are not operated under a constant load and also the induced stresses are constantly changing. An example of this kind of test is a rotating shaft such as the axle on a railroad car. The bending stresses often change from tension to compression as the axle rotates, which are indicated in Figure 4.10.
The reason for the fatigue failure is due to the constant change in stress, so that the material suddenly fractures. The process which leads to fatigue failure is initiation and growth of cracks in the material. Hence, the cracks in the material start to grow and the remaining uncracked material no longer able to carry the applied loads. Fatigue may also be defined as a cyclic (or stochastic) time-dependent loading or straining of material. The change in loading with respect to time is more common from an engineering perspective and is normally considered to be mechanically induced.

4.5.1 Test Procedure

Two swivelling bodies are mounted in their brackets and fixed over the base and it contains hollow shaft assemblies. The specimen is inserted in the left hand (LH) and gripped in the right hand (RH) assemblies. The locking ring, locking rod and spring help to prevent the rotation of hollow shaft assembly while loosening the specimen.
Figure 4.11 Fatigue testing machine

The weight is placed on the receiving plate of the loading mechanism to balance both the left and right rotary spindles and the required stress is obtained through these predetermined weights. The load applied to the specimen is indicated on the scale by pointer. The selection of rotational speed of the specimen is based on the size of the pulleys and the direction of rotation is also checked. After resetting the counter to show all zeros, the motor of the machine is started up, thus starting the test. A typical Rotating Bending Fatigue Testing Machine FTG 8(D) used to conduct the fatigue test is shown in Figure 4.11.

During testing, the number of revolutions is recorded by using a built-in photocell sensor which is attached at the end of the right rotary spindle. The signal of the photocell is transmitted to a digital counter mounted on the machine. The limit switch is provided to switch the motor off when the specimen breaks immediately and it also stops the counting of revolutions. The test is repeated under different loads until the specimen breaks and these sufficient numbers of points can be used to plot the S-N curve.
The specimen used in the fatigue test is prepared by using the casting process. The range of melting of pure aluminium is 660 °C. Beyond that temperature, the other alloying element like, tin, silicon and copper are introduced into the melted aluminium. The temperature of mixture is increased up to 850 °C and it is maintained for three hours. Then the aluminium alloy is poured into the die to obtain the required shape of the specimen. The photographic view of the specimen prepared for the fatigue test and its dimensions are shown in Figures 4.12 and 4.13 respectively.

![Figure 4.12 Photograph of specimen used for fatigue test](image1)

![Figure 4.13 Fatigue test specimen (ASTM D5812)](image2)

### 4.5.2 Stress Cycles

Cyclic or fluctuating loading has no repeated patterns or in conditions somewhere overloading occurs and Figure 4.14 shows three possible fluctuating stress-time modes that may perhaps begin a fatigue crack.

Figure 4.14a shows the completely reversed constant amplitude where the alternative stresses vary from a maximum tensile stress to a minimum compressive stress of equal magnitude. Figure 4.14b shows that the repeated constant amplitude occurs when the maxima are symmetrical relative to the zero stress level. This is called cyclic tension and compression loadings.
Figure 4.14c shows that the stress level may vary randomly in amplitude and frequency which is simply termed random cycling.

![Random Cycling Example](image)

**Figure 4.14** Typical fatigue stress cycles (a) Fully reversed (b) Offset (c) Random

In this variable-amplitude loading, only those cycles exceeding some peak threshold will result in fatigue cracking. Normally, the kind of load acting on the engine bearing applications is tension/compression loading (Figure 4.20a). Therefore, the fatigue test conducted in this work is at constant amplitude and the maximum and minimum stresses are constant for each cycle of test.

The various fatigue parameters are listed below which are utilized to identify the fluctuating stress cycles.

\[
\text{Mean stress, } \sigma_m = \frac{\sigma_{\text{max}} + \sigma_{\text{min}}}{2} \quad (4.17)
\]

\[
\text{Stress range, } \sigma_r = \sigma_{\text{max}} - \sigma_{\text{min}} \quad (4.18)
\]
Stress amplitude, \( \sigma_a = \frac{\sigma_{\text{max}} - \sigma_{\text{min}}}{2} \) \hspace{1cm} (4.19)

Stress ratio, \( R = \frac{\sigma_{\text{min}}}{\sigma_{\text{max}}} \) \hspace{1cm} (4.20)

Amplitude ratio, \( A = \frac{\sigma_a}{\sigma_m} \) \hspace{1cm} (4.21)

Fatigue ratio, \( = \frac{\text{Fatigue Strength}}{\text{Tensile Strength}} \) \hspace{1cm} (4.22)

The above said parameters are extensively affecting the fatigue behaviors of the materials. Increasing in maximum stress in addition to mean stress and stress range leads to more severe fatigue conditions. In general, the three stages of fatigue failures are crack initiation, crack propagation and fast fracture. The cycles required to crack is called crack initiation and cycles required to develop the crack in steady mode to a critical size is called crack propagation. In the rapid fracture, the development of crack length reaches the critical value and there is no rapid fracture term used in the fatigue life term.

The fatigue life is usually classified into two types namely low cycle fatigue and high cycle fatigue. Low cycle fatigue is low number of cycles is equal to less than \( 1 \times 10^3 \) cycles and otherwise is called high cycle fatigue. The purpose of the fatigue life method is to determine the life (number of loading cycles) of a material until failure. There are three major fatigue life methods based on some types of loading or for some materials.

The various methods available for finding the fatigue life are stress-life, strain-life and linear-elastic fracture mechanics. In the stress-life method, results give only the fatigue life due to the alternating stress level but it does not give any reason to why the failure has occurred. The rotating
bending fatigue testing method, gives only the stress-life relation and this helps to generate the stress amplitude versus number of cycles diagram (S-N).

4.6 RESULTS AND DISCUSSIONS

The various mechanical properties like hardness, tensile strength, impact strength, flexural strength and fatigue strength are calculated for the developed alloys of AlTSi and AlTSiH and their results are compared with the conventional bearing alloy of AlT. The specimens are prepared as per the ASTM standards and their results are discussed below

4.6.1 Hardness Test Results

The hardness test is carried out for the developed alloys, using the Equation (4.1) and the results are shown in Figure 4.15.

![Figure 4.15 Hardness test comparison value](image)

Figure 4.15 Hardness test comparison value
From the graphs, it is concluded that the AlT alloy has lower hardness value when compared to AlTSi and AlTSiH alloys. The reason is the presence of higher copper and silicon contents in both the developed alloys. Due to the heat treatment process, also the hardness of alloy has improved.

4.6.2 Tensile Test Results

Figure 4.16 Fractured specimens after tensile test

The tensile tests for all three alloys are carried out using UTM and their readings are noted frequently. This test is useful to find the various mechanical properties like Ultimate Tensile Strength, Yield Strength, Young’s Modulus and Ductility. The fractured specimens of the alloys after the tensile tests are shown in Figure 4.16.

The stress strain curve for the developed alloy is shown in Figure 4.17. From the graph, it is observed that the limit of proportionality of AlTSi and AlTSiH alloys are higher than AlT alloy. This shows the strength of the material and makes it to exhibit the high load carrying capacity of the material. The Young’s Modulus is calculated from the slope of stress strain
diagram within the proportionality limit. The AIT and AITSi alloys show a clear transition from elastic to plastic state which is used to locate the yield point. AITSi alloy has higher proportionality limit when compared to AIT alloy, which results in higher Yield Strength and Ultimate Tensile Strength. But there is no clear transition of elastic to plastic state is observed in the AITSiH alloy. Here the location of yield point is difficult and only minor variations are observed till the graph reaches the ultimate load.

![Stress-strain curves for developed alloys](image)

**Figure 4.17 Stress-strain curves for developed alloys**

Using the Equations (4.2-4.9), the required properties such as Yield Strength, Ultimate Tensile Strength, Permissible stress, Young’s Modulus and Percentage of Elongation are calculated and are tabulated in Table 4.1. The sample calculation of permissible stress and tensile strength of Al-20Sn alloy is given in Appendix 2. Thus among these tested alloys, AITSiH alloy has high Yield Strength, and hence load carrying capacity is higher than the other
two alloys. There is quite a large increase in Tensile Strength due to higher content of silicon and copper in the AlTSiH alloy. Also it increases with the decrease in tin content, but ductility is more with a percentage elongation of 7.8% which makes it more vulnerable for deformations. However, the developed alloys have high hardness value and Tensile Strength than AIT alloy and are suitable for engine bearing applications particularly for I.C. engines.

Table 4.1 Results of tensile test

<table>
<thead>
<tr>
<th>Samples</th>
<th>Permissible stress, N/mm²</th>
<th>Young’s modulus, N/mm²</th>
<th>Yield Strength, N/mm²</th>
<th>Ultimate Strength, N/mm²</th>
<th>% of Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIT alloy</td>
<td>65</td>
<td>18663</td>
<td>130</td>
<td>397.6</td>
<td>3.3</td>
</tr>
<tr>
<td>AITSi alloy</td>
<td>90</td>
<td>23160</td>
<td>180</td>
<td>448</td>
<td>6.1</td>
</tr>
<tr>
<td>AITSiH alloy</td>
<td>167</td>
<td>27777</td>
<td>334</td>
<td>515.37</td>
<td>7.8</td>
</tr>
</tbody>
</table>

4.6.3 Izod Impact Test Results

The Izod test is also known as the notch toughness test which is used to measure the energy absorbed by a specially prepared specimen when it is struck by a pendulum type of hammer. The energy losses by the pendulum due to windage and bearing losses are neglected and the test is conducted as per ASTM standards. Minimum of five tests are conducted and the results are given in Table 4.2.
Table 4.2 Results of impact test

<table>
<thead>
<tr>
<th>Test No. / Alloys</th>
<th>AIT alloy</th>
<th>AITSi alloy</th>
<th>AITSiH alloy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.325</td>
<td>3.354</td>
<td>5.565</td>
</tr>
<tr>
<td>2</td>
<td>2.982</td>
<td>4.091</td>
<td>5.924</td>
</tr>
<tr>
<td>3</td>
<td>3.183</td>
<td>3.853</td>
<td>6.324</td>
</tr>
<tr>
<td>4</td>
<td>2.754</td>
<td>3.463</td>
<td>5.93</td>
</tr>
<tr>
<td>5</td>
<td>2.921</td>
<td>3.755</td>
<td>5.735</td>
</tr>
<tr>
<td>Average impact strength, J</td>
<td>2.833</td>
<td>3.7032</td>
<td>5.8956</td>
</tr>
<tr>
<td>Range, J</td>
<td>0.858</td>
<td>0.737</td>
<td>0.759</td>
</tr>
</tbody>
</table>

The Izod test is conducted for five samples and the average value is taken for the load of 785 N. Figure 4.18 shows the energy absorbed by the tested specimen with different test numbers. From the results, a small range of variations are observed and the reason behind the variations is due to the preparation of the specimens. They are made up by hand with little control over the notching in particular. The results indicate that the AITSiH alloy is the toughest plastic and AIT alloy being the most brittle. Then the range is calculated, which is the difference between the largest number and the smallest number of the calculated values of impact strength.

The Izod Impact test result show that the impact strength value for AIT alloy has lower than the AITSi and AITSiH alloys. The better impact strength values are obtained in the AITSiH alloy, which is clearly shown in Figure 4.18.
4.6.4   Flexural Test Results

The ability of materials to resist deformation under load is called flexural strength and it has to be performed in order to determine how the material will react under force or changing forces such as bending or flexing. It is also important to find out the flexural properties of the material so that the design is within the desired tolerance. In general, the purpose of cyclic or fatigue testing is to determine how long the material can carry on certain forces before failure. But the purpose of flexural test is to find the range of characteristics including the maximum force of failure, cycles and time to failure, flexural strength and flexural strain. The test is performed until the total deflection of the specimen is 5% and measurements are made and recorded continuously. The test is conducted for a minimum of three samples.
and the average value is taken for the load 100 kN. The flexural test reports for the developed alloys and their consolidated test results are given in Appendix 3. The flexural strength is calculated by using Equation (4.13) and the obtained values are given in Table 4.3.

Table 4.3 Results of flexural test

<table>
<thead>
<tr>
<th>Alloy</th>
<th>CS Area (mm²)</th>
<th>Peak Load (N)</th>
<th>Break Load (N)</th>
<th>Flexural Strength (N/mm²)</th>
<th>Flexural Modulus (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIT alloy</td>
<td>100</td>
<td>952.193</td>
<td>47.685</td>
<td>78.554</td>
<td>8.628E6</td>
</tr>
<tr>
<td>AITSi alloy</td>
<td>100</td>
<td>1191.310</td>
<td>59.571</td>
<td>98.274</td>
<td>6.662E6</td>
</tr>
<tr>
<td>AITSiH alloy</td>
<td>100</td>
<td>1177.571</td>
<td>59.735</td>
<td>97.136</td>
<td>7.006E6</td>
</tr>
</tbody>
</table>

4.6.4.1 Ultimate stress for flexural

![Ultimate stress for flexural](image)

**Figure 4.19** Ultimate stress for flexural test
The ultimate stress value can be calculated by dividing the peak load to the cross sectional area of the specimen and the obtained values are given in Figure 4.19. The test result shows that, the Ultimate Stress value for AIT alloy is inferior to AITSi and AITSiH alloys, and among these the better value is achieved in AITSi alloy.

### 4.6.4.2 Breaking stress for flexural

![Breaking stress for flexural test](image)

**Figure 4.20 Breaking stress for flexural test**

The breaking stress value can be calculated by dividing the break load to the cross sectional area of the specimen. Figure 4.20 shows the obtained value of breaking stresses for the developed alloys.

The flexural test result shows that the breaking stress value for AIT alloy is lower than the AITSi and AITSiH alloys and better value is achieved in AITSiH alloy. The higher flexural strength is obtained in AITSi alloy and
flexural modulus is achieved in AlTSiH alloy. The results obtained during the flexural test are given in Appendix 3.

### 4.6.5 Fatigue Test Results

During the fatigue test, the applied stresses may be axial (tension-compression), flexural (bending) or torsional (twisting). The fractured specimen after fatigue test is shown in Figure 4.21.

![Figure 4.21 Fractured specimens after fatigue test](image)

#### 4.6.5.1 S-N curve

Fatigue test focuses on the nominal stress required to cause fatigue failure in some number of cycles. The test results presented the data as a plot of stress amplitude (S) against the number of cycles to failure (N), which is known as an S-N curve. A log scale is used to plot the cycle failures and the data is obtained by cycling smooth or notched specimens until failure. Since the amplitude of the cyclic loading has a major effect on the fatigue performance. The amplitude is expressed as the R ratio value, which is the minimum peak stress divided by the maximum peak stress. (R=\(\sigma_{\text{min}}/\sigma_{\text{max}}\)). The maximum and minimum stresses are in similar amounts but having the opposite signs (compressive and tensile stresses) is called reversed cyclic stresses, in which the stress ratio equals -1.

During fatigue testing, the specimen is rotated about the longitudinal axis and the upper and lower parts of the specimen gauge length are subjected to tensile and compressive stresses respectively. Hence at any
point on the specimen surface, the variation of stress is sinusoidal. The fatigue
test is repeated for various specimens and each specimen is subjected to
different stress level and number of cycles. Here the number of cycles at
specimen failure and corresponding applied stress are counted by using a
revolution counter. S-N curve is very sensitive to many variables including
the mean stress, testing temperatures, surface hardness, surface finish of the
specimen and the environment. Hence, more care is needed to prepare the
specimens.

Figure 4.22 shows the applied stress amplitude versus the logarithm
of the number of cycles to failure for each specimen. The test is conducted at
room temperature. Increasing the weight applied (stress amplitude) to the
specimen results in the reduction in the number of cycles to failure. The S-N
curve is used to determine the fatigue life of the material subjected to cyclic
loading. The endurance limit is sometimes called fatigue strength which is
very important because a design engineer can use this numerical value for the
purpose of selecting materials which are subjected to high-cycle fatigue.

From the figure, it is clearly observed that there is no endurance
limit for aluminium alloy materials, and finally these materials failed due to
repeated loading. To come up with an equivalent endurance limit, designers
typically use the value of the fatigue strength at $5 \times 10^8$ cycles. From the S-N
curve the obtained value of fatigue strength is for the lab specimen only, and
in order to account the real specimen including the correction factor given in
Equation (4.22).
Figure 4.22 S-N curves for developed alloys

Actual endurance fatigue strength,
\[ S_f = K_{\text{surf}} K_{\text{size}} K_{\text{load}} K_{\text{temp}} K_{\text{reliability}} S_f' \]  \hspace{1cm} (4.22)

Here

Surface factor, \( K_{\text{surf}} = a S_{\text{ult}}^b \)

For machined surface, \( a = 4.51 \) and \( b = -0.265 \) and

\[ K_{\text{surf}} = 0.9234 \text{ (for AlT alloy)} \]
\[ K_{\text{surf}} = 0.8945 \text{ (for AlTSi alloy)} \]
\[ K_{\text{surf}} = 0.8691 \text{ (for AlTSiH alloy)} \]

Size factor, \( K_{\text{size}} = 1 \), for axial loading

Load factor, \( K_{\text{load}} = 0.85 \), for axial loading
Temperature factor, $K_{\text{temp}} = 1$, for 25 °C
Reliability factor, $K_{\text{reliability}} = 0.897$ for 90%

The results obtained from the fatigue test are given in Table 4.4.

**Table 4.4 Results of fatigue test**

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Fatigue strength, $S_f$ (N/mm$^2$)</th>
<th>Ultimate Tensile Strength, (N/mm$^2$)</th>
<th>Fatigue ratio</th>
<th>Fatigue strength, $S'_f$ (N/mm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlT alloy</td>
<td>112.21</td>
<td>397.60</td>
<td>0.33</td>
<td>79</td>
</tr>
<tr>
<td>AlTSi alloy</td>
<td>143.36</td>
<td>448</td>
<td>0.32</td>
<td>97.78</td>
</tr>
<tr>
<td>AlTSiH alloy</td>
<td>180.38</td>
<td>515.37</td>
<td>0.35</td>
<td>119.53</td>
</tr>
</tbody>
</table>

It is concluded that the fatigue strength or endurance limit for the AlTSi and AlTSiH alloys calculated at $5 \times 10^8$ cycles are 143.36 N/mm$^2$ and 180.38 N/mm$^2$ respectively which is higher than AlT alloy of 112.21 N/mm$^2$. Finally, the actual fatigue strength of the developed alloys is calculated and is 1.24 and 1.51 times more than the conventional bearing alloy.

**4.7 CONCLUSIONS**

The aluminium-based alloy material may be effectively used in the industry due to its better mechanical properties like high hardness, maximum tensile strength, good impact strength, high flexural and fatigue strength. In this chapter, the various mechanical properties of the developed aluminium-based alloys are tested, under atmospheric conditions. From these the following conclusions are drawn
1. The hardness value of the developed alloy is increased when compared to pure aluminium and conventional bearing alloy
   - The hardness value of the AITSi alloy is 1.5 times more than the pure aluminium and 1.22 times more than the AIT alloy
   - The hardness value of the AITSiH alloy is 1.75 times more than pure aluminium, 1.17 times more than AITSi alloy and 1.43 times more than the AIT alloy.

2. The tensile properties of the developed alloys are better than that of conventional bearing alloy. Among these, AITSiH alloy has high Tensile Strength and thus it has high load carrying capacity.

3. The impact test results shows that the,
   - AIT alloy has an average of 2.83 J with a range of 0.89 J
   - AITSi alloy has an average of 3.70 J with a range of 0.74 J
   - AITSiH alloy has an average of 5.90 J with a range of 0.76 J

4. In the flexural test, the lower Ultimate and Breaking stress values are obtained in the AIT alloy (9.52 N/mm² and 0.48 N/mm²). The better Ultimate stress value is achieved in AITSi alloy (11.92 N/mm²) and Breaking stress value in AITSiH alloy (0.48 N/mm²).

5. From the S-N diagram, it is observed that there is no endurance limit for the aluminium based alloy and the value of fatigue or endurance strength of the alloy is considered at 5 x 10⁸ cycles. On account of correction factors the obtained actual fatigue strength of the developed alloy is better than the conventional bearing alloy, and among these, AITSiH has achieved better strength.