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Fatigue and Crashworthiness of Automobile Materials after DBTT and Hygrothermal Conditioning: a REVIEW

Amol Bhanage*, K. Padmanabhan

Composite Laboratory, School of Mechanical Engineering, VIT University, Vellore, Tamilnadu, India

Abstract : Automobiles meant for a tropical country might not be found suitable in an arctic environment merely because some materials had already gone through ductile to brittle transition (DBT). The cost of materials and manufacturing will also be high for automobiles meant for use in adverse environments. As the automotive materials reach high temperatures during operation and reach - 30 to - 60 °C during stationary parking, the fatigue response of materials known to exhibit DBT, however low, becomes important in qualifying a material for safe use in an automobile. The correlation between DBT and fatigue is a subject area that is less understood. This paper intends to study the influence of DBT of composite materials in their fatigue response and important from the crash worthiness point of view of automobiles. As newer materials like composites and light alloys are used in the manufacture of automobiles, it becomes necessary not only to understand their mechanical properties like Charpy impact before and after the transition, but also fatigue response in the domain where the transition takes place. Some interesting results are anticipated and the feedback, will lead to the development of composite materials and alloys that are resistant to DBT failures and fatigue failures after DBT, if at all DBT should occur at a noticeable level.

Keywords : Automobiles, Composite materials, DBT, Fatigue, Hygrothermal, Steel.

Introduction

Evaluation of vehicle structural durability is one of the key requirements in the design and development of today's automobiles [1]. As more and more new materials like composites and light alloys are used in the manufacture of automobiles, it becomes necessary not only to understand their mechanical properties like Charpy impact before and after the transition, but also conducts fatigue tests in the domain where the ductile to brittle transition (DBT) takes place. Driven by the demand for fuel-efficient, light-weight, and high stiffness automotive structures that have fatigue durability are designed nowadays with newer materials like composite materials.

As a continuous fibre reinforced composites provide good mechanical properties, they have been increasingly used in many lightweight structures such as structural automotive parts which were subjected in service to fatigue loadings. Therefore a good prediction of fatigue life is required [2]. Although there are key differences between metal and composite damage mechanics and durability concerns, certification philosophy for composites must meet the same structural integrity, safety, and durability requirements as that of metals. Despite the many advantages, composite structure becomes challenging due to complex interactive failure mechanisms, sensitivity to temperature and moisture, and scatter in the data, especially in fatigue [3]. Also automotive crashworthiness, which is material key property generally used for structural components considered in this paper from the fatigue point of view.

The automotive crashworthiness has two key zones, namely Energy Management Zones, i.e. (engine compartment, trunk) deform to absorb energy and Passenger Compartment resists deformation to prevent intrusion, as showed in Figure 1. The material required for energy management zone should have the highest energy absorbing capacity and high strength and ductility. Whereas, material required for the passenger compartment should have the highest strength. Martensite and boron steel are generally preferred [4-5]. The ductile to brittle transition in metals is characterized by a sudden and dramatic drop in the energy absorbed by a metal subjected to impact loading. This transition is practically unknown in FCC metals, but is well known in BCC metals.

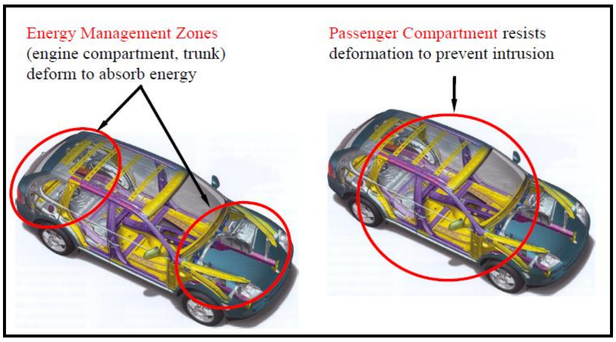


Figure.1. Crashworthiness Fundamentals – Two Key Zones

Many fatigue design in automotive, must operate at temperatures below room temperature. This operating temperature may be climatic temperature as low as - 54ºC vehicles. Fatigue behaviour at this low temperature has received much less attention than at room and elevated temperatures. Generally, most of the reports of low temperature fatigue behaviour based on constant amplitude test and very little verification of real life fatigue. So, for this study, we consider low temperature fatigue behaviour by reviewing the effect of low temperature on monotonic material properties and then by considering S-N, ε –N, and da/dN – ΔK, constant and variable amplitude loading and, life predictions.

This paper mainly focuses on behaviour of automotive materials under fatigue for steel at room temperature and before ductile to brittle transition temperature (DBTT). The correlation between DBTT and fatigue is a subject area that is less understood. Although for composite materials, under hygrothermal conditioning for static, impact and fatigue conditioning. This study indicates the importance of DBTT and hygrothermal study of steel and composite materials respectively, for automotive from the crashworthiness point of view.

Experimental Scenario for Steel

Transition Temperature and Steel

The metals that remain ductile at extreme subzero temperatures include nickel, copper, aluminium have a face-centered cubic (FCC) crystal structure, appears ductility at low temperature. Metal's having a body-centered cubic (BCC) structure undergoes a marked decrease in ductility over a range of temperatures and the range of transition temperatures may occur from well above and below. In case of FCC metals, the fracture strength increases at a rate equal to or greater than the flow strength. Greater spreads between the flow and fracture strengths permit more deformation to occur prior to fracture; hence these metals retain or increase their ductility at low temperatures. However, BCC exhibits a more rapid increase in flow strength than in fracture strength as the temperature is lowered. As the spread between flow and fracture strengths decreases, less plastic deformation occurs. Finally, at some reduced temperature, fracture takes place with no plastic deformation [6]. DBTT (Ductile to Brittle Transition Temperature) can be a serious problem for certain grades of steel undergoing large deformation at low temperature [7]. As ferritic steel becomes colder, they undergo a transition from a shear-dominated (ductile) fracture mode to a cleavage-dominated (brittle) fracture mode. This is measured through fracture mechanics testing, such as CTOD, KIC, Charpy, or J-integral testing. A similar effect has been documented for fatigue at low temperatures and has been called the Fatigue Ductile-Brittle Transition (FDBT). The temperature at which this transition occurs is known as the Fatigue Transition Temperature (FTT). It has been observed that lower temperatures generally cause decreased fatigue crack growth rates until the FTT is achieved. Below the FTT, the trend is reversed, and higher fatigue crack growth rates are encountered [8-10]. There exits two events that are very typical for low temperature environment and might be dominating fatigue crack propagation rates are; first the ductile brittle transition (DBT) phenomenon in body-centered-cubic (BCC) and hexagonal-close-packed (HCP) systems, which introduces a fracture mode transition [11].

For static loading, the transition region occurs at low temperatures than for impact loading, depending on the yield strength of steel. Thus, for structure subjected to static loading, the static transition curve should be used to predict the level of performance at the service temperature. However, for structures subjected to impact or dynamic loading, the impact transition curve should be used to predict the level of performance at the service temperature [12].

High strength steels are becoming more and more interesting for the automotive industry as they allow car weight reduction due to lower thickness ensuring the same performance and improved safety by higher energy absorption [13]. Accordingly the steel is demanded to have good ductility. It was demonstrated that ductility does not have an unambiguous definition. However, the properties needed in automotive body applications are ductile fracture behaviour, high energy absorption capability and resistance against hydrogen embrittlement over the entire temperature range of operation. In the intense competition between different materials, Stainless steel products have significant advantages with respect to corrosion resistance, fatigue resistance and crashworthiness over aluminium alloys and high-strength low-alloy steels. Use of martensitic steel became highly relevant to car body engineering, especially in areas where intrusion by high speed impact loading during a crash should be avoided. But, it's showing brittle failure mechanisms with increasing strength particularly under, increased strain rate and at lower temperature [14].

Fatigue Behaviour at room temperature

Fatigue behaviour in metals is known to consist of crack initiation and growth. Crack initiation starts with dislocation movement and then sub micro cracks are formed, which grows until final rupture. This process covers most of metals fatigue life [15].

Adila Afzal described stress-based approach to fatigue is typically used for life prediction of components subject to high cycle fatigue, where stresses are mainly elastic, as in the case of connecting rods of automotive. Constant amplitude load control with a sinusoidal waveform was used in all tests of connecting rod. Loading frequency varied from 2 to 5 Hz with a lower value used for high load levels and a higher value for the low load levels. Each test was performed under a constant load frequency condition. Forged steel connecting rod fatigue strength, defined at 10^6 cycles, is 387 MPa [16]. Experimental and computational durability assessment approaches of the lower suspension arm under actual service loading were presented by N.A. Kadhim. In the lower suspension arm design, cyclic behaviour is a major concern. SAE 1045 steel material chosen for lower suspension arm of short life or high strain exhibits better fatigue resistance [17]. SAE 0030, SAE 0050A, C-Mn, Mn-Mo and AISI 8630 steel were subjected to constant-amplitude fatigue tests at room temperature and at the common low climatic temperature of 45°C. Three of the five steels had nil ductility transition temperatures above the low test temperature [18].

Experimental Scenario for Composites

Static damage Mechanism

Geofferey Pritchard predicted several potential causes of deterioration in composites, among the most important are moistures, chemicals, temperature and mechanical fatigue. The combination of absorbed moisture and temperature fluctuations can cause cracking and other damage. On this, the matrix has greater sensitivity to moisture than the fibre [19].

Abdelghani Naceri conducted a hygrothermal test on glass fibre fabric/ epoxy resin with relative humidity of 60 and 90 percent. It confirms the coefficient of diffusion D and the maximum quantity of water retained with saturation Mm depend not only on the nature of material, of the temperature, but also of the relative humidity rate and the maximal concentration of water at the saturation of the composite. It also clearly shows that the presence of fibres in a polymeric matrix decreases about 4 times the quantity of water absorbed by this matrix (see Table 1). Mm becomes more significant beyond 60% of relative humidity [20].

Table 1.Experimental Results of Moisture Absorption of Composite

Humidity RH in (%)	60	96
D in (cm2/s . 10-8)	1.20	0.21
Mm of composite in (%)	0.18	1.10
Mm of resin in (%)	0.62	4.00

Hygrothermic behaviour of glass / epoxy FRP studied by Shivakumar at different temperature of 30, 50 and 70 ºC for 200 days in 95 % R.H. All specimens' shows drop in flexural strength (almost 52 %) with respect to immersion time because of moisture take. The amount of water uptake by epoxy based composites is significantly greater which leads to evaluation of the localized residual stress field [21]. Shi Yong has done the investigation on the moisture absorption and desorption of two types of composite materials, first unidirectional glass fiber-reinforced DGEBA type epoxy resin composite (filament winding unidirectional flat plate) and secondly, chopped glass fiber-reinforced hydroxymethylated nylonmodified phenol resin composite. The absorption tests was carried out in deionized water and in artificial seawater at room temperature, whereas desorption test was conducted in a dessicator also at room temperature. Moisture absorption rate and saturation moisture content are higher in unidirectional glass fiber-reinforced DGEBA type epoxy resin with deionized water than artificial sea water and vice versa in chopped glass fiber-reinforced composite. Figure 2 shows moisture absorption curves and desorption curves for specimens [22].

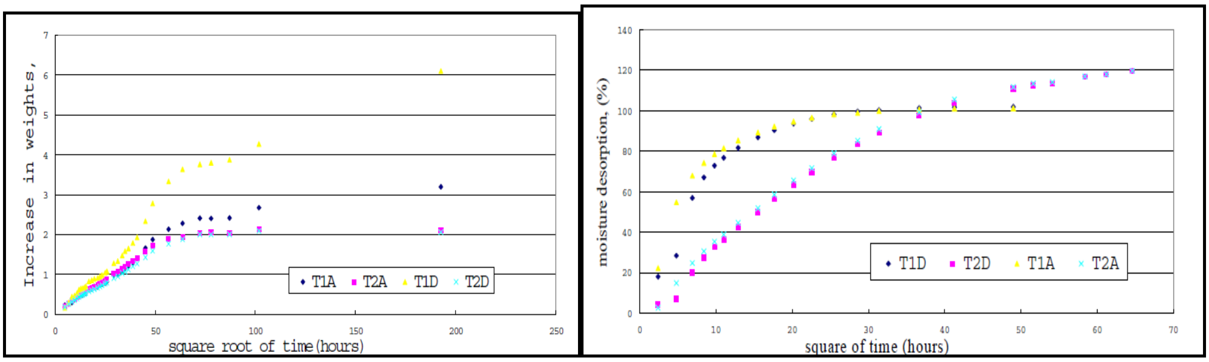


Figure.2. Moisture absorption & Desorption curves Vs Square root of time

P. K. Ray investigated moisture, in both normal and frozen conditions, has a detrimental effect on mechanical properties of glass/epoxy composites (60:40). However, the extent of damage is more severe in case of frozen moisture. De-bonding at the fiber/matrix interface in a fiber bundle is caused after the amount of absorbed moisture reaches to a saturation level. The tensile strength below the amount of saturated moisture is decreased by the plasticization of the matrix and above that it is related to the interfacial degradation .The tensile and bending strength degradation with respect to net weight gain (Mg) as showed in Figure 3. The Figure 4 shows the effect of moisture absorption in glass/epoxy composites predicted moisture results in the loss of adhesion between the fiber and the matrix and degradation of epoxy matrix in the case of an aged specimen [23].

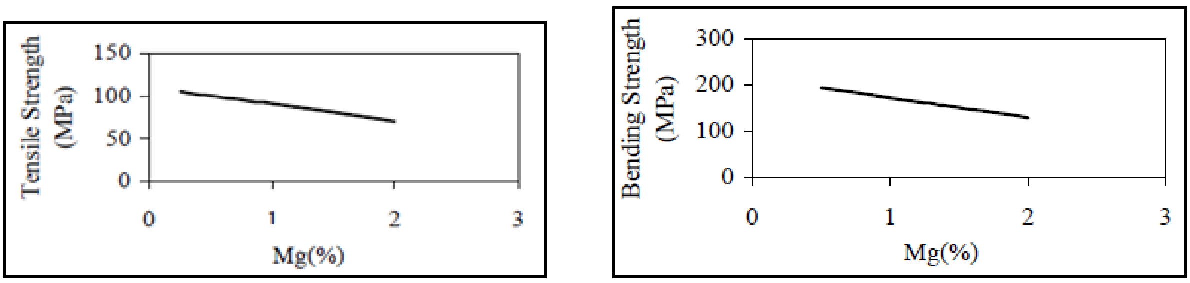


Figure.3.Effect of Moisture on Tensile Strength (MPa) and Bending Strength (MPa)

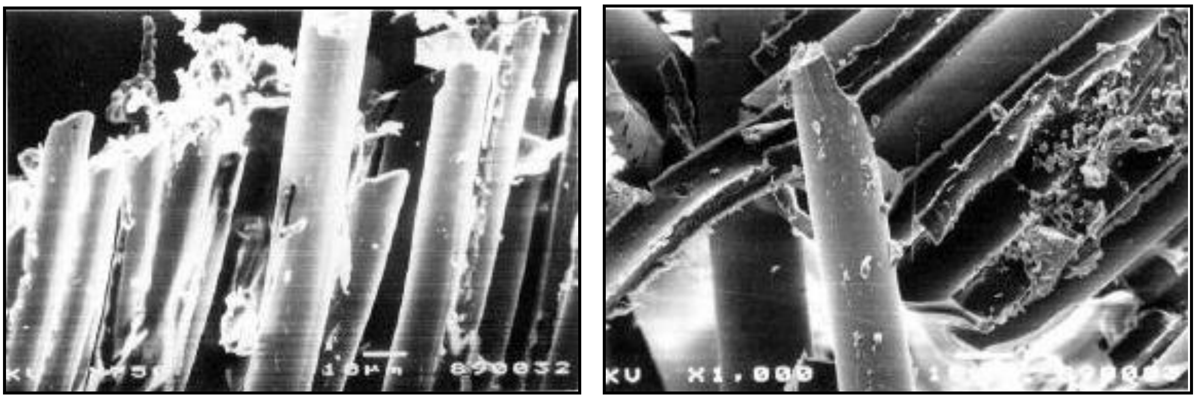


Figure.4. Loss of adhesion between the fiber and the matrix (Left) and Out crop of epoxy polymer in case of the aged specimen (Right)

Beckry Abdel-Magid worked on a project which used glass/epoxy material had an ultimate strength of 767 MPa and a modulus of 36.5 GPa. Test was done for short duration (500 and 1000 h) of applied tensile stress and submergence in distilled water at room temperature. After 500 h of conditioning with tensile stress and submergence in distilled water, the strength of the material increased by 5% over the control from 767 MPa to 808 MPa, and after 1000 h the strength dropped to 776 MPa. The modulus of the material was decreased by 11% at 500 h and by 14% after 1000 h. After 3000 h of constant tensile load and exposure to water, at room temperature, the strength of the material exhibited a decrease by 35%, from 767 MPa to 499 MPa and modulus of the G/E material decreased by 9% from 36.5 GPa to 33.2 GPa. These changes in properties are caused by fiber straightening and matrix plasticization. Due to sorption of water, from 500 h to 3000 h at room temperature, led to decrease in strength, 499 ± 28 MPa and strain-to-failure, 1.5% ± 0.05% indicates a brittle failure in the matrix. However, the composite as a whole became more brittle. Extended exposure to moisture and load at room temperature may result in catastrophic failure, while higher temperature may lead to ductile failure of continuously laminated E-glass/epoxy composites [24]. Laurent Cormier worked on changing in mechanical properties of unidirectional glass-epoxy composites exposed to moisture, cold temperature and freeze-thaw cycles. Tests were made at ambient temperature and -40 ºC on four sample families. It is seen that the effects on the composite's strength when at a temperature of -40 ºC are significant. The strengthening is of at least 14% for the wet specimens while it reaches 23% for the wet and thermally cycled condition. Also, moisture saturation of the composite results in a strength reduction of at least 30% for the thermally cycled samples tested at -40 ºC and up to 35% for the other conditions. The short beam shear strength is a matrix dominated property. It is, therefore, expected to vary significantly with temperature. The short beam shear strength reduction goes from 10% for the thermally cycled specimens tested at -40 ºC to 21% for the wet and thermally cycled condition at RT. It can also be seen that the predicted strengths are mostly lower than the measured ones, even though premature failure occurred during testing. Moreover, the predicted increase in strength for saturated specimens is not observed as measured strengths to wet conditions are always lower than those for the dry condition [25].

G. S. Springer investigated on glass fibre reinforced sheet molding compound (SMC) applied to automotive. He concluded ultimate tensile strength, flexural strength, tensile modulus and flexural modulus decrease at elevated temperature. This decreasing property depends on temperature, type of fluid and length of exposure. Also, there is a significant decrease in shear strength and shear modulus at elevated temperature and during exposure to humid air [26]. Qayes Abdullah Abbas used sheet of epoxy with 12 layers of (0º - 90º) glass fiber mat with volume fraction equal to 30% for Charpy impact test to investigate effect of water absorption on impact strength . The test sample was immersed in distilled water for 15, 27 and 39 days at a constant temperature of 20º C. The sample without immersion had impact strength of 122.01 KJ/m^2. After 15, 27 and 39 day's immersion, impact strength dropped to 120.01 KJ/m^2, 115 KJ/m^2 and 106 KJ/m^2 respectively. These results shown impact strength was decreased with increasing time of immersion for samples [27]. Slavica Putic presented work on influence of high and low temperature (at 20º C, 50º C and -50º C) on the impact properties of glass-epoxy composites with the orientation of 0º/90º and +/- 45º. The impact strength obtained at elevated temperature was greater than at room temperature and shows minimal value at low temperature with characteristics of brittle cracks [28].

Fatigue damage Mechanism

The interpretation of fatigue damage progression based on initiation and growth of only one dominant crack does not reflect the real damage situation in a composite, where various damage mechanisms such as, matrix cracking, fibre/matrix debonding, delamination and fibre rupture occur simultaneously. Giorgio Zaffaroni studied effect of hot-wet aging on the properties of a glass-reinforced epoxy resin in both dry and moisture saturated conditions. For wet condition testing, specimens were adged up to 50º C to obtain 40% and 90% saturation level. Three sets of specimens were prepared $(+/-45°)_{4s}$, $(+/-45°/90º/0º)_{2s}$ and specimen composed of +/- 45°/90º/0º layers with 16 mm thickness for testing. Fatigue test results on specimen with $(+/-45°)_{4s}$ shown in Figure 5, no degradation of long-term fatigue performance and $(+\_45°/90°/0°)_{2s}$ specimen shown in Figure 6, also followed same trend of $(+/-\ 45°)_{4s}$. The intersection of dry and wet curves seems to shift at the high number of cycles (between 10^4 and $l0^5$ cycles).

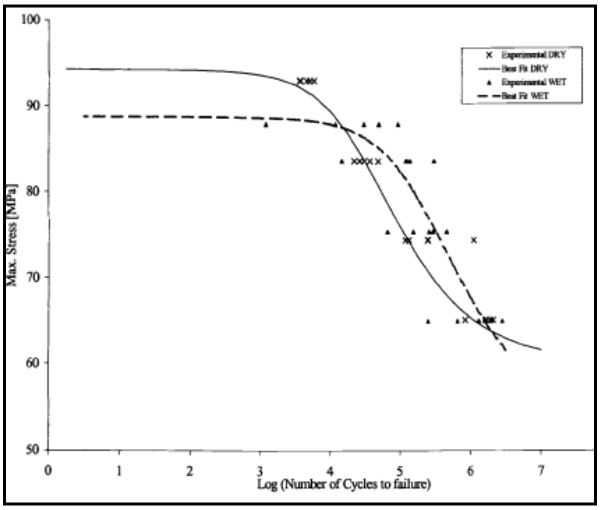


Figure. 5. S-N results for (+/-45°)

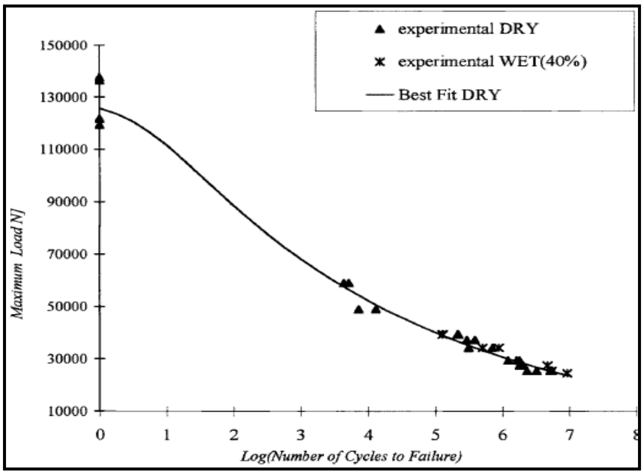


Figure.6. S-N results for $(+/-45°/90º/0º)_{2s}$

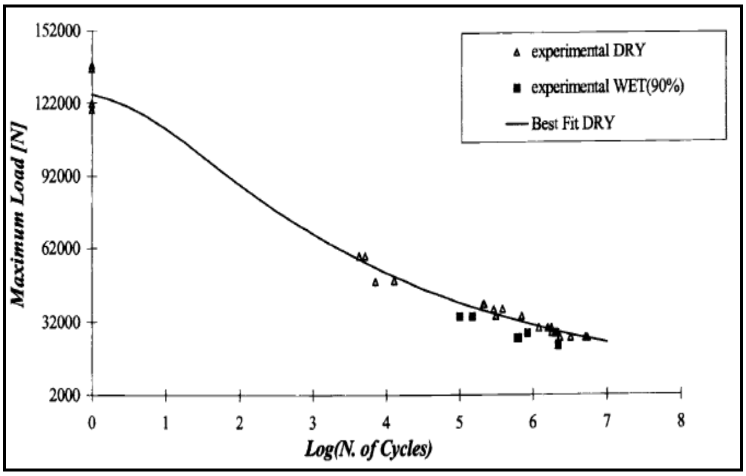


Figure.7. S-N results for quasi-isotropic plates for fully moisture saturation

For wet (90%), damaging effect of moisture on fiber properties can reduce the 0 ° fatigue performance [29]. The interaction between hygrothermal ageing and fatigue behaviour of unidirectional glass-epoxy composites have been investigated under three point bending loading. During fatigue test, increase in crack propagation rate shown at elevated temperature (70º C) due to interaction between surrounding moisture and crack tip. Lifetimes at low relative humidity (3% R.H.) and two different temperatures (23º C and 70º C) shows low moisture content in test environment, a temperature rises had deleterious effects on material lifetime and more significant decrease in lifetimes were encountered when moisture (40% R.H.) was associated with temperature (70º C) in the test environment. It also concludes that ageing duration in immersion has more influence than temperature level on fatigue properties of composite [30]. Watanabe M. concluded that the main factor governing the environmental effects, on the fatigue behaviour of Fiberglass Reinforced Plastics (FRP), was the interfacial behaviour, and that the transporting rate of water to the defects formed thereby plays an important role. The effect of weakened interface on the fatigue strength is believed to be significant under lower stress, longer life, or higher temperature [31]. Temperature as well as fibre orientation influences the fatigue behaviour of short glass fibre reinforced injection moulded ring spanner used in automotive. The study has shown decreasing fatigue strength for increasing testing temperature and decreasing average fibre orientation [32].

The experimental study of pre-fatigue testing of GFRP materials and then exposes them to hygrothermal conditions at different temperatures shown strength degradation and also concluded that more the fatigue cycles of specimen, the rate of decrease of tensile strength is more as compared to the specimen with lesser fatigue cycles. A Universal Tensile testing machine was used for the testing of the GFRP specimen for its tensile strength. From testing, it is clear that the rate at which the tensile strength is decreasing is more for 55° C bath as compared to 45° C bath and a minimum in case of natural degradation for each type of loading. For different loadings it is seen that for a given temperature maximum decrease in tensile strength has occurred in case of 60% loading cycles as compared to 40% loading cycles and minimum for the specimen which are without fatigue loading cycles. It could be easily noticed that at higher temperatures the weight gain is more effective in comparison to the lower temperatures. Also in the case of specimen is in the same bath with increasing cyclic loading shows greater percentage of weight gain [33].

Daniel Houston studied first step in developing accurate performance assessments of automotive composite materials in environmentally realistic conditions. Such data are critical to a robust design which will perform reliably and predictably over its entire lifetime under often unpredictable operating conditions. Elevated temperature testing at 180º F, exposure to ambient gasoline soak for 100 hours and aging for 1000 hours at 300º F and testing at ambient indicated very little material property degradation. Depressed temperature testing occurred at - 40º C represent's actual conditions encountered by vehicle located in northern areas of North America and Europe. As design requirements for lower weight, longer life and higher levels of structural performance continue to emerge, a thorough understanding of structural composite performance under service conditions and environmental extremes will become increasingly important [34].

Proposed Method for Improved Crashworthiness during Fatigue Loading

In India, generally hottest the state region like Tamilnadu, Rajasthan and Delhi and coolest state region like Himalaya, J & K and Uttarakhand are identified. The following states data are mentioned with relative humidity and Temperature.

Table 2.Experimental Results of Moisture Absorption of Composite

Area	States	Highest Temp.	Lowest	Relative Humidity (%)
Hottest Area	Rajasthan	50.6 °C	- 2.2 °C	85 % - 20 %
	Tamilnadu	43 °C	5.4 °C	92 % - 29 %
Coolest Area	Himalaya	30 °C	- 45 °C	64 % - 31 %
	Uttarakhand	41 °C	- 5 °C	98 % – 30 %

The following parameters like the highest and lowest temperature as well highest and lowest relative humidity (R.H.) with saturation equilibrium condition are considered. Table 3 illustrates parameter and probability with temperature and R.H.

Table 3.Parameter & Probability Considered

Temperature	Relative Humidity (R.H.)
Highest Temperature (T1)	Highest R.H.
Lowest Temperature (T2)	Lowest R.H.
Highest Temperature (T1)	Lowest R.H.
Lowest Temperature (T2)	Highest R.H.

Problem defined in Automotive

1) Anti Roll Bar

Amol Bhanage and Dr. K. Padmanabhan [35] studied Anti roll bar (ARB) used in SUV's which reduced the amount of 'body roll of automotive' during turning and compare fatigue characteristics of ARB for AISI 1020, SAE 4340, SAE 5160 and SAE 9262 materials before Ductile to Brittle Transition Temperature (DBTT). Fatigue simulation was calculated using ANSYS n code Designlife software shows higher fatigue life for SAE 5160 with comparison to AISI 1020, SAE 4340 and SAE 9262 under same loading conditions above ductile to brittle transition temperature. They have also proposed conducting the fatigue analysis after DBTT for AISI 1020, SAE 4340, SAE 5160 and SAE 9262 materials in order to evaluate its real environment fatigue life for extreme conditions.

Figure 8 and Figure 9 shows minimum value of fatigue life of SAE 1020 and SAE 4340, when anti roll bar subjected to high cycle fatigue, where stresses are mainly elastic.

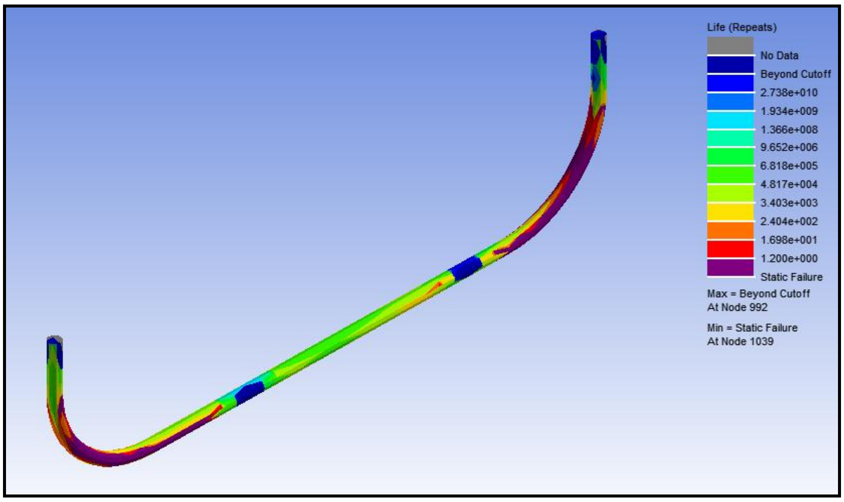


Figure.8. Fatigue life of AISI 1020 anti roil bar

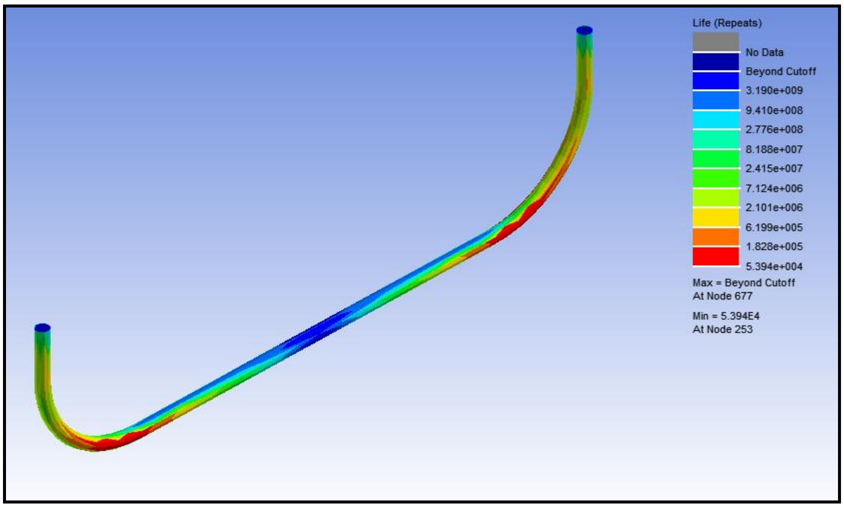


Figure.9. Fatigue life of SAE 4340 anti roil bar

Figure 10 and Figure 11 also showed fatigue damage and mean biaxiality ratio values for SAE 4340 and SAE 9262 respectively. From simulation, fatigue life, fatigue damage and mean biaxiality ratio were summarized in Table 4.

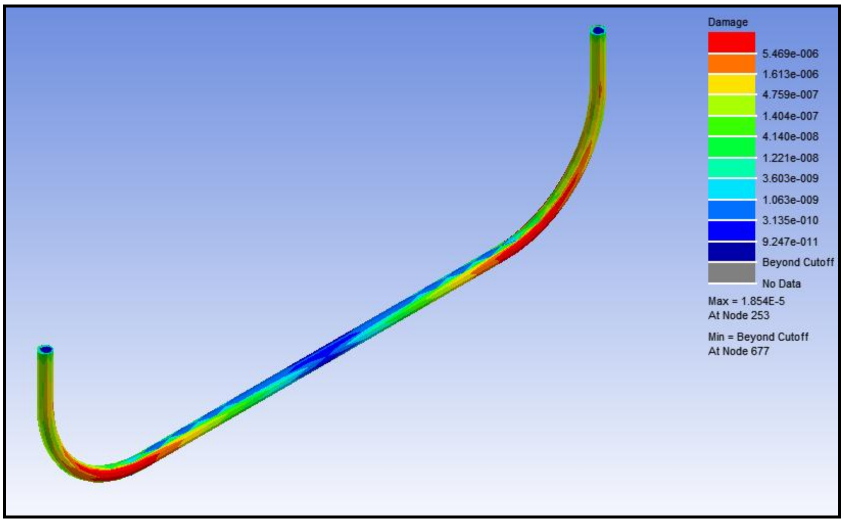


Figure.10. Fatigue damage of SAE 4340 anti roil bar

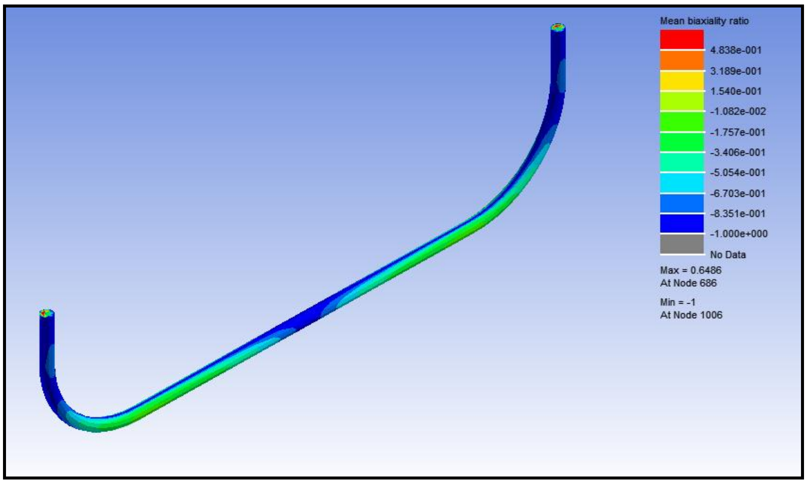


Figure.11. Mean biaxiality ratio of SAE 9262 anti roil bar

Table 4. Fatigue simulation results of anti roll bar

Material	Fatigue Life in Cycles	Damage	Mean biaxiality ratio
AISI 1020	1.03 E+03	2.87E-02	0.64
SAE 4340	5.39 E+04	1.85 E-05	0.65
SAE 5160	3.77 E+06	2.64 E-02	0.64
SAE 9262	3.42 E+03	2.91 E-04	0.64

Padmanabhan K [36] outlined the investigation, which deals with SAE 1026 steel for producing stabilizer bars. Here, worked done on comparing the working parameters of the material in real-time testing conditions and plotting an endurance curve to study the performance. Further, more effective material is identified and suggested for future production of stabilizer bars for automobiles. To plot S-N (Endurance) curves as showed in Figure 12, for the SAE 1026 material, for varying Von-Mises stress levels the displacement was varied. From the stress levels corresponding to the three displacements viz. 39, 42 and 45 mm, the cycles to failure obtained and plotted. As the set displacements increased from 39 to 45 mm the von mises stress level at which failure occurs also increased from 800 MPa to 1400 MPa. The number of cycles at which fatigue failure occurred decreased from 48123 to 16004 correspondingly.

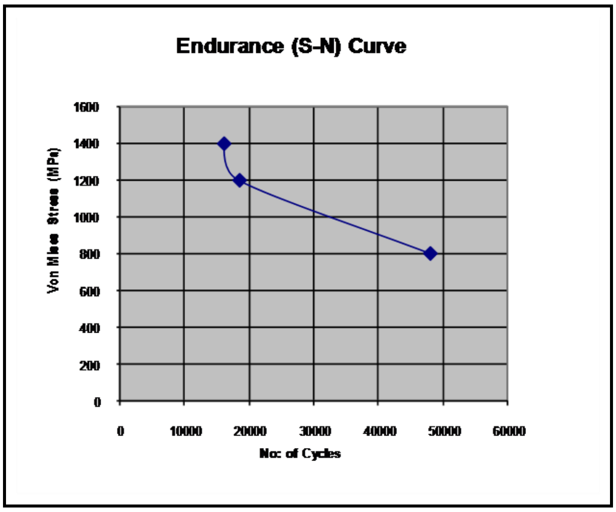
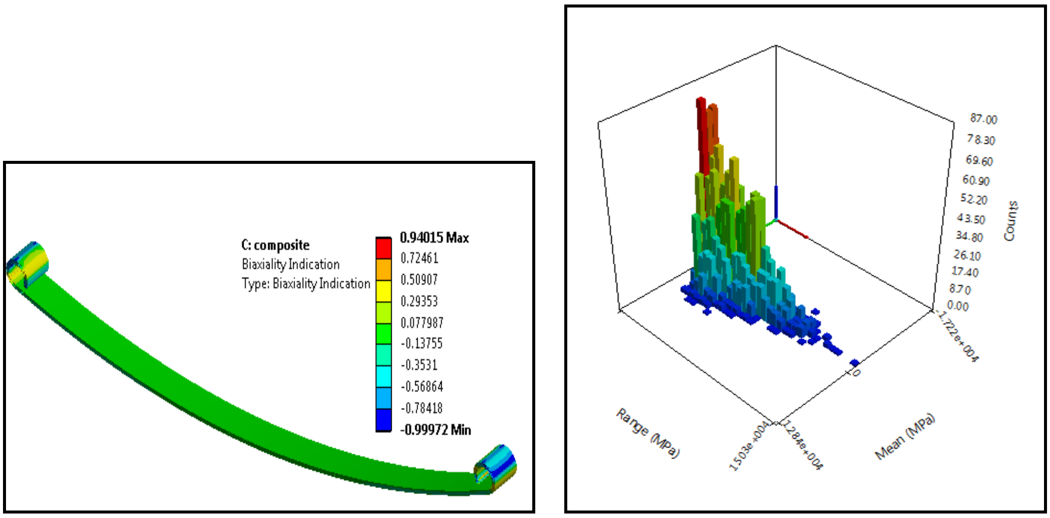


Figure.12. the fatigue test S-N curve for SAE1026 tube bar

The stabilizer bars were fabricated from the materials through the various processes involved in manufacturing such as induction hardening, tempering, sizing and cutting, bending and orbital TIG welding of end lugs. The bars were then shot peened and tested for fatigue at various stress levels. Finite element analysis using Solid works™ for the material candidates were carried out in support of the real time testing. Fatigue endurance curves for the material stabilizer bars were constructed and analysed for qualification.

2) Leaf Spring

Amol Bhanage and Dr. K. Padmanabhan[37] also studied the fatigue performance of a glass fibre/epoxy composite leaf spring comparison with SAE1045-450-QT steel in dry condition. Due to Weight reduction and stress, stiffness criteria, multi steel leaf spring is proposed to be replaced with E- Glass Epoxy composite leaf springs. Factors like fatigue life, fatigue damage, biaxiality indication, rain flow counting and fatigue response are plotted for the composite leaf spring and the fatigue performance is predicted using life data. Figure 13 (a) showed Biaxiality Indication plot for E-Glass Epoxy material, where biaxiality of 0 shows uniaxial stress value of –1 for pure shear and value of 1 corresponds to a pure biaxial state. Figure 13 (b) shown 3-D cycle histogram bins where cycle corresponds to low stress range and higher stress ranges. High stress range gives most of damage. This is a plot of the Rainflow matrix at the critical location.



(a) (b)

Figure.13: (a) Biaxiality Indication Plot for E- Glass Epoxy and (b) Rainflow Matrix Chart

Figure 14 shows Fatigue Sensitivity which was variation of fatigue results as a function of the loading at the critical location on the leaf spring model. It's generally found for life, damage, or factory of safety.

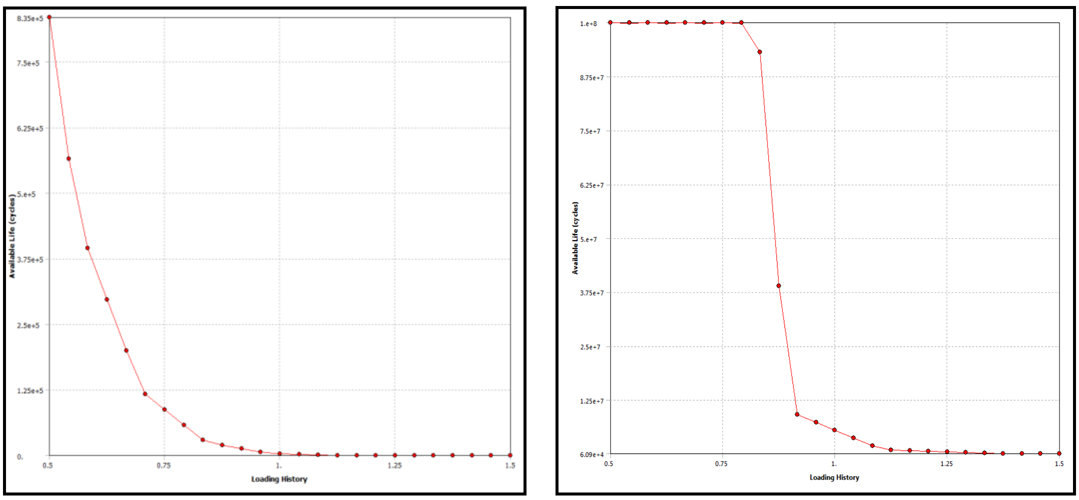


Figure.14. Fatigue Sensitivity Plot for E- Glass Epoxy and SAE 1045-450-QT leaf spring.

Here proposed to conduct the fatigue analysis of a hygrothermally saturation conditioned composite leaf spring in order to evaluate its real environment fatigue life. Himalayan sub zero temperature fatigue performance will also be evaluated.

Conclusions

The fatigue response of materials known to exhibit DBT, however low, becomes important in qualifying a material for safe use in an automobile. The correlation between DBT and fatigue is a subject area that was less understood and this investigation aims to fill that gap, for future work. Also, understanding of automotive material performance at elevated and depressed temperatures is required to know under hygrothermal conditioning for composites, to design components that will function in a predictable and reliable manner over a wide variety of operating conditions. Some interesting results are anticipated and the feedback from our investigation. It is believed, will lead to the development of composite materials and alloys that are resistant to DBT failures and fatigue failures after DBT, if at all DBT should occur at a noticeable level. This investigation is also important from the crash worthiness point of view of automobiles.

It concluded from the study, a mild hygrothermal attack might increase crashworthiness due to improved ductility and DBTT will reduce crashworthiness due to the structure getting brittle. Similarly, hygrothermal attack might or might not increase fatigue life. This depends on degradation of static properties, if static properties are severely degraded. Fatigue will also be severe. DBTT conclusively reduces fatigue life. But the extent of fatigue damage and reduction of fatigue life remains to be seen, after DBTT.

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