Numerical and Theoretical Analysis for Investigation of Shear strength of A Joint Established Using Adhesive for Automotive Application

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Abstract— It is becoming increasingly important to accurately predict the behavior of adhesive joints. Adhesive joints are widely used in industries e.g. automobiles, aircrafts, home appliances and so on. They are being used as a closure system in the packaging industry, through the use of adhesives as a system for construction of complex structures such as skyscrapers, airplanes, trains or buses etc. In adhesive bonding, the load is transmitted from one adherend to another adherend smoothly through the adhesive layer in the overlap region i.e. the adhesive serves as medium for load transmission. The research is presented with variants of different adhesive materials proposed for the shear strength investigation of adhesive joint to be used in the automotive industry. The problem is investigated using mathematical analysis as well as analytical methodology with Finite Element Analysis. For meshing of the geometry of the brake shoe assembly hyper mesh software is used. In FEA, the competent software 'Abacus' is used for determining the shear stress induced in two different materials of adhesive layer applied to the brake shoe. Different variants with different adhesive materials and geometry of base material are analyzed for concluding the research work.

Keywords: Adhesives, Shear stress of a joint, Brake shoe

I. INTRODUCTION

In the last two decades, adhesive bonding has become more common in engineering. The advantages of the adhesive joint over the conventional mechanical fasteners are savings in weight and cost. The common type of joint in use today, is the lap joint where two adherends overlap and are fixed together by a layer of adhesive between them. Failure in a joint may occur either in the adherend or in the adhesive or at the interface. A failure at the interface is termed as 'adhesive, ' since it involves the failure of the bond between the adhesive and the adherend. When the fracture occurs either inside the adhesive or inside the adherend, the failure is then termed as 'cohesive' [5]. In a cohesive failure, the material at the two fracture surfaces is the same. The interfacial adhesion of modern adhesives is high so that failure mostly occurs either in the adhesive as in the case of metal to metal joints, or in the adherends as happens with wood joints. Adhesively bonded joints offer the aerospace designer an attractive mass efficient alternative to the mechanical fastening of structural components.

In the past, however, the poor reliability of bonded joints has in general dissuaded designers from taking full advantage of the projected benefits of bonded structural designs. Thus, growth in the use of bonded systems in load-carrying components is not keeping pace with the continuing development and improved reliability of new high strength adhesives. Bonded joints should be designed to transfer load in shear with a minimum of peel across the bond line, since adhesives are generally more efficient in supporting shear forces and perform poorly when supporting peel type forces. Design of bonded joints thus requires knowledge of the shear and peel stress distributions in the bond line as well as the shear strength of the adhesive [1]. The failure strength of adhesively bonded joints depends on many factors such as material properties (both adhesive and adherend), specimen geometries, test environments, surface preparation procedures, etc. Among them, adhesive properties can be regarded as the most dominating factor affecting the failure strength.

II. NUMERICAL ANALYSIS

The finite element method (FEM), is sometimes referred to as finite element analysis (FEA), is a computational technique used to obtain approximate solutions of boundary value problems in engineering. Due to the complexity of the structures stresses are usually calculated by numerical methods such as the finite element method. The finite element analysis (FEA) is a numerical technique for finding approximate solutions of partial differential equations (PDE) as well as of integral equations [2]. The solution approach is based either on eliminating the differential equation completely, or rendering the PDE into an approximating system of ordinary differential equations, which are then numerically integrated.

A finite element analysis is able to determine stress and strain distributions throughout a bonded structure resulting from an applied force or displacement. It is possible to calculate the stiffness of the joint and to locate regions of stress and strain concentration where failure is expected to initiate. Using a suitably fine mesh the influence of geometrical features, such as the size and shape of fillets at the ends of the adhesive layer, on stress and strain distributions can be evaluated. Certain steps in formulating finite element analysis of a problem are common to all such analyses whether structural, heat transfer, fluid flow or some other problem. These steps are embodied in commercial finite element software packages. Figure shows general procedure for finite element method. These steps are described below,

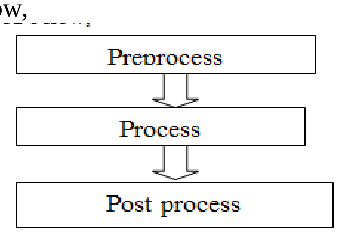

Fig 1: Stages of Analysis

A. 3D Modelling in CATIA:

The three dimensional model of brake shoe is prepared in CATIA V5 R16 environment. For analysis we have created 3D model and with the help of CATIA software it can generate model of each geometry in three dimensions views

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and that will help to visualize properly and to clear idea about model quickly.

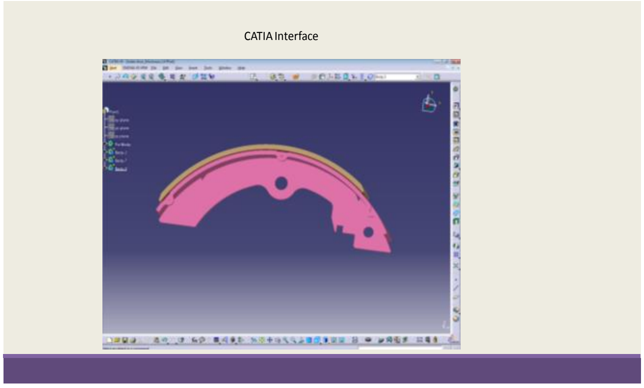

Fig 2: 3D model of brake shoe

B. Meshing of Geometry using Preprocessor (Hyper Mesh):

Hyper Mesh user-interface is easy to learn and supports many CAD geometry and finite element model files - increasing interoperability and efficiency. Advanced functionality within Hyper Mesh allows users to efficiently mesh high fidelity models. This functionality includes user defined quality criteria and controls, morphing technology to update existing meshes to new design proposals, and automatic mid-surface generation for complex designs with of varying wall thicknesses. Automated tetra-meshing and hexa-meshing minimizes meshing time while batch meshing enables large scale meshing of parts with no model clean up and minimal user input. For analysis purpose we have to discretised the geometry in to number of parts. For this purpose we used the pre-processor Hyper Mesh. The element used is C3D8R hexahedral element for meshing of the geometry. There are total no of 113493 nodes and 130510 elements in the meshing geometry.

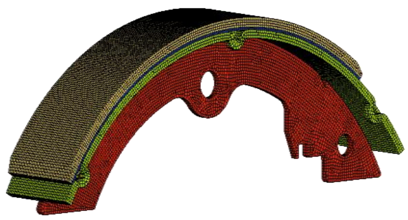

Fig 3: Meshing of brake shoe

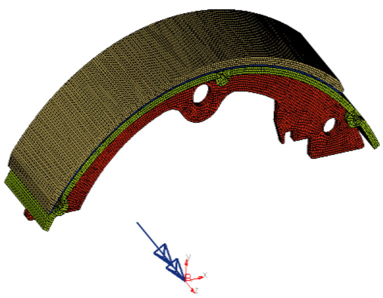

Fig 4: Loading condition of brake shoe

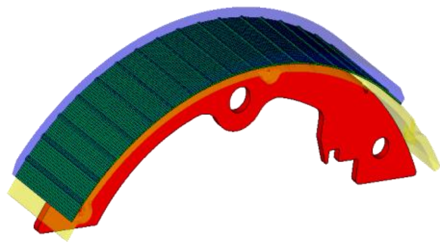

Fig 5: Meshing using grooves on base

Torque is applied at the centre of the wheel and upper surface of adhesive joint is constrained to simulate the shear. For this purpose all degrees of freedom are arrested except rotation about Z axis for calculating the shear stresses induced in the joint. Six different design variants are created by changing the adhesive materials and by changing the base design of the shoe. The surface texture shall be offered manipulator using grooves or criss-cross construction. The change in geometry is likely to affect the performance in a favorable manner. Since the adhesive can lodge in the crevices and improve the retention of the joint. Figure below shows the numerical results obtained for one of the design variant.

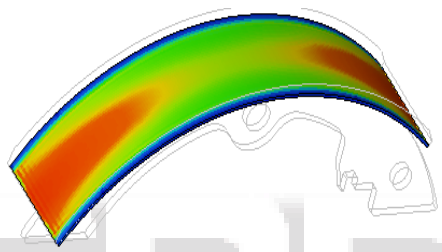

Fig 6: Shear stresses induced in the adhesive layer

III. THEORETICAL ANALYSIS

An adhesive is a material used for holding two surfaces together. An adhesive must wet the surfaces, adhere to the surfaces, develop strength after it has been applied, and remain stable. The stress in the adhesive layer is dependent on the geometrical proportions and the elastic constants of the materials of the joint, and on the nature of the forces acting on the joint. In this case study shear stresses are developed in the adhesive of the brake shoe due to torque applied. The shear stresses can be calculated by using the formula given below,

M=Mass of the Vehicle is kg.

V=maximum speed velocity of vehicle in kmph.

K.E = ½ mv2 ... (3.1)

We know that, work done is nothing but kinetic energy.

So, Work done = Braking force * Displacement.

W.D. = Fb x d... (3.2)

Putting values of Work done and displacement we get Braking force.

Now, Torque = Braking force * radius.

T = Fb x R... (3.3)

T = is in N-M

Putting values of Braking force and radius we get value of torque.

Applied Force,

F = T/R…. (3.4)

R= Radius of drum.

Load per unit Width,

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$$P = F/W\ldots \quad (3.5)$$

W= Width of Drum.

$$\sigma = P/t \ldots \quad (3.6)$$

$$c = L/2\ldots \quad (3.7)$$

$$\tau_{max} = \frac{\sigma}{8} * (1 + 3k) * \sqrt{(8Gat \div E * ta)}\ldots \quad (3.8)$$

$$k = \frac{\cosh(u2*c)*\sinh(u1*L)}{[\cosh(u2*c)*\sinh(u1*L) + 2*\sqrt{2}*\cosh(u1*L)*\sinh(u2*c)]} \ldots \quad (3.9)$$

$$u_2 = \sqrt{[3*\sigma*(1 - \mu^2)/ (2*E*t^2)]} \quad \ldots \quad (3.10)$$

$$u_1 = 2*\sqrt{2}*u_2 \quad \ldots \quad (3.11)$$

Where,
P = load per unit width.
L = length of overlap (bond length).
t = adherend thickness.
E = adherend modulus.
G_a = adhesive shear modulus.
t_a = adhesive layer thickness.
μ = Poisson's Ratio of Adhesive.

The table below shows the results for values of shear stresses calculated by numerical and theoretical analysis of the two materials for base design of the brake shoe base material. The values of shear stresses are calculated for torque value of 2930 N-M by considering maximum speed of the vehicle.

parameters	Disp (mm).	Shear stress(Mpa)	Relative slip	Cont.stress (Mpa)
Material 1	1.84E-2	13.13	1.375E-13	7.054
Material 2	7.18E-2	10.21	1.323E-13	6.449

Table 1: Numerical analysis results for materials

Sr.No.	Numerical (Mpa)	Theoretical (Mpa)
Material 1	13.23	11.01
Material 2	10.21	7.17

Table 2: Comparative shear stress values of Theoretical, Numerical Analysis

IV. RESULTS AND CONCLUSION

The provision of an accurate failure criterion for adhesives would greatly facilitate accurate modeling of adhesively bonded structures. Much work has been performed on structural adhesives and still no universal criterion has been established. The structural analysis of adhesive joint of the brake shoe is carried out and the shear stresses induced in the adhesives layers are calculated in this study. The results for the different variants evolved during the study assert the significance of the parameters determined for this work. From the numerical and mathematical analysis out of the two different materials the material 2 gives lower value of shear stress. Maximum values of shear stresses are observed at the side end of the adhesive layer but permissible limit of shear stresses has not been exceeded at any point. The base design satisfies the criteria of no slippage. The recommended variant needs to be implemented in practice. This might solve several problems in terms of designing adhesive joint over the designated mating area of the brake shoe and the brake pad.

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