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Strength Evaluation of Adhesive Joint in Brake Shoe of an Automotive System.

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ABSTRACT

This dissertation work is aimed to investigate the strength adhesive joint for a braking system. The use of adhesives offers many advantages over binding techniques such as sewing, mechanical fastening, thermal bonding etc. Adhesive offers the ability to bind different materials together. Advantages using adhesive are distribution of stress more efficiently across the joint, the cost effectiveness, easily mechanized process and an improvement in aesthetic design and increased design flexibility. For this dissertation work problem is investigated using mathematical analysis as well as analytical methodology with Finite Element Analysis. The dissertation is presented with variants of different adhesive layer thickness and the geometry manifested by the pattern of the adhesive layer applied are proposed for the shear strength investigation of adhesive joint to be used in the automotive industry. In FEA the competent software is used for determining the shear stress induced in different thickness of adhesive layer applied between brake pad and brake shoe. Comparative study for the methodologies is presented while arriving at the most suitable variant of the brake shoe with respect to the thickness of the adhesive layer and the geometry manifested by the pattern of the adhesive layer applied. A total of five variants are analyzed for concluding the thesis work.

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I. INTRODUCTION

An adhesive is any substance applied to the surfaces of materials that binds them together and resists separation. The term "adhesive" may be used interchangeably with glue, cement, mucilage, or paste. Adjectives may be used in conjunction with the word “adhesive” to describe properties based on the substance's physical or chemical form, the type of materials joined, or conditions under which it is applied.[1] The use of adhesives offers many advantages over binding techniques such as sewing, mechanical fastening, thermal bonding etc. Adhesive offers the ability to bind different materials together. Advantages using adhesive are distribution of stress more efficiently across the joint, the cost effectiveness, easily mechanized process, an improvement in aesthetic design, and increased design flexibility. Disadvantages of use of adhesive include decreased stability at high temperatures, relative weakness in bonding large objects with a small bonding surface area and greater difficulty in separating objects during testing. [1] Adhesives may be found naturally or produced synthetically. The earliest human use of adhesive-like substances was approximately from century years ago. From then until 1900, increase in use of adhesive and discovery were relatively gradual. Development of synthetic adhesives accelerated rapidly since the last century and innovation in the field continues to the present [2]

Advantages of adhesives

1. The adhesives materials allow joint substrates with different geometries, sizes and composition. [4]

2. The use of adhesives eliminates the corrosion associated with dissimilar metals joining with different galvanic potential, such as the joining of steel with aluminum [4]
3. The use of adhesive as bonding material does not produce any deformation in the materials or substrates, eliminating metal grinding processes (grinding and putty), reducing the manufacturing cost and improving the aesthetics of the product. [5]
4. Do not produce any mechanical aggression to the substrate, avoiding any damage to the structure of the material. [5]
5. Great flexibility in the product design as well as an improvement in its aesthetics. [6]

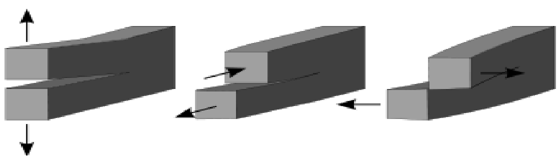
Disadvantages

1. Requirement of better Surface treatment. [1]
2. More Curing time require adhesives. [2]
3. Adhesion is difficult to control. [2]
4. Restricted structural behavior at high temperature. [7]
5. When subjected to loading, debonding may occur at different locations in the adhesive joint.

The major fracture types are the following [5]

INTERFACIAL FRACTURE

The fracture is adhesive or interfacial when debonding occurs between the adhesive and the adherent. In most cases, the occurrence of interfacial fracture for a given adhesive goes along with smaller fracture toughness. The interfacial character of a fracture surface is usually to identify the precise location of the crack path in the interface. [5]



Mode I – Opening
Mode II - in-plane shear
Mode III - Out of plane shear
Fig.1 Different modes of failure

MODES OF FAILURE

As a general design rule, the material properties of the object need to be greater than the forces anticipated during its use. (i.e. geometry, loads, etc.). The engineering work will consist of having a good model to evaluate the function. For most adhesive joints, this can be achieved using fracture mechanics. Concepts such as the stress concentration factor and the strain energy release rate can be used to predict failure. In such models, the behavior of the adhesive layer itself is neglected and only the adherents are considered. Failure will also very much depend on the opening mode of the joint. [5]

- Mode I is an opening or tensile mode where the loadings are normal to the crack.
- Mode II is a sliding or in-plane shear mode where the crack surfaces slide over one another in direction perpendicular to the leading edge of the crack. This is typically the mode for which the adhesive exhibits the highest resistance to fracture.
- Mode III is a tearing or antiplane shear mode.

As the loads are usually fixed, an acceptable design will result from combination of a material selection procedure and geometry modifications, if possible. In adhesively bonded structures, the global geometry and loads are fixed by structural considerations and the design procedure focuses on the material properties of the adhesive and on local changes on the geometry. Increasing the joint resistance is usually obtained by designing its geometry so that. The bonded zone is large It is mainly loaded in mode I. Stable crack propagation will follow the appearance of a local failure. [5]

Table 1: Relative strengths of different adhesives [3]

Adhesive Type	**Shear Strength**		**Peel Strength**		**Operating Temp.**	
	MPa (N/mm^2)		**N/mm^2**		**Min ^oC**	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**
Rubber	0.35	3.5	1.8	7	-20	150
PVA (white glue)	1.4	6.9	0.88	1.8	-	-
Cyanoacrilate	6.9	13.8	0.88	3.5	-	80
Anaerobic	6.9	13.8	0.88	1.8	-	200
Polyurethene	6.9	17.2	1.8	8.8	200	150
Rubber modified acrylic	13.8	24.1	1.8	8.8	-40	90
Epoxy	10.3	27.6	0.35	1.8	-	200
Polyimide	13.8	27.6	0.18	0.88	-	350
Rubber modified epoxy	20.7	41.4	4.4	14.0	-	180

Shear and peel strengths of generic adhesive types are discuss in table 1. The values above are random values obtained from general reference sources and suppliers catalogues. They are often rounded values from imperial. They are only of use to indicate the relative strengths of different adhesives. [3]

PROBLEM DEFINITION

The brake shoe assembly includes the base and the liner pad. Typically this forms adhesive bonded joint for the base with the pad. To determine the specifications for the individual parts in this assembly, there is a need to evaluate the strength of the adhesive that holds these two critical parts together. The parameters affecting the strength of the joints need to be identified. An alternative method to extensive physical experimentation need to be explored for evaluating the strength. Altercations over the values for the significant parameters for Design, including material for the Adhesive could be dealt with using Analytical method/ Finite Element Modeling. Only the results for the existing benchmark design or the evolving best option, although, could be considered to be verified using the physical experimentation

SCOPE OF THE WORK:

As an input, the geometry (3D model) for the component shall be secured. For this dissertation work, the existing geometry (or the benchmark) shall be pre-processed and solved using the Finite Element Modeling method. Physical experimentation shall be deployed for validating the model. Revisions shall be evaluated using FEM. Best design alternative determined upon alterations to the values of the significant parameters shall be proposed for implementation.

STEPS FOR EXECUTION OF THE WORK

1. Study the types of Adhesive Joints
2. Identify the problem
3. Study the material and finalized the different geometry
4. Prepare 3 D model in CATIA
5. Meshing of geometry using Hypermesh
6. Conduct CAE Analysis
7. Conduct experimentation
8. Compare the results with the existing material

II. MATHEMATICAL TREATMENT FOR CASE STUDY

For the problem to be diagnosed, the empirical formulae in the Engineering domain can be applied for seeking a solution. The study over the subject coatings, paints, varnishes, multilayered sandwiches, polymer blends, filled polymers, adhesive joints, and composite materials. To make adhesion possible, it is necessary to generate intrinsic adhesion forces across the interface. Because the final performance or use properties of these multi component materials depend significantly on the quality of the interface that is formed between the solids, it is understandable that a better knowledge of adhesion phenomena is required for practical applications. Pressures on costs and vehicle weight (meeting Corporate Average Fuel Economy (CAFE) regulations), while meeting safety goals, and further accentuate the challenge, driving the industry towards new, less costly materials and processes. [4]

The trend towards recycling the entire vehicle, already relatively strong in Europe, has recently begun to affect material and fastening choices in auto interiors in Asia. Thus, new materials and processes are continuously under development. Many of these require changes in fastening or in companion construction materials, such as adhesives done in the past have offered formulae derived by the researchers in the respective field. Application of the relevant mathematical rule to the problem at hand can lend a credible solution for finding the best alternative. Typically, the formulae in the field of Applied Mechanics or Structures can be helpful for finding a numerical value for specifying the quantum of the unit or direction for the solution.

For the application being studied the maximum shear stress allowed by the manufacturer is 30 MPa. For a single lap joint, the maximum adhesive shear stress, **τ_o, max**, can be calculated using the following equations.

$$\tau_{0\,\max} = \frac{\sigma}{8}\,(1 + 3k)\,\sqrt{\frac{8\,G_a\,t}{E\,t_a}}$$

Where

$\sigma = P/t$

$c = L/2$

$$k = \frac{\cosh(u_2\,c)\,\sinh(u_1\,L)}{\sinh(u_1 L)\,\cosh(u_2 c) + 2\sqrt{2}\cosh(u_1 L)\,\sinh(u_2 c)}$$

P = Load per unit width (as derived from equation)

L = Length of overlap (bond length)

t = adherend thickness

E = adherend modulus

Ga = adhesive shear modulus

ta = adhesive layer thickness

Ea = Adhesive tensile modulus

N = adherend poisson's ratio

Now, based on the above formulation and from equation we will calculate the maximum shear stress of adhesive joint for different thickness of adhesives.

Given Data:

Diameter of drum, D = 200 mm

Radius of drum, R = 100 mm

Length of overlap (bond length), L = 150 mm

Width of Drum, W = 40 mm

Applied Torque, T = 850 Nm = 850000 Nmm

Adherend Thickness, t = 3 mm

Adhesive layer thickness, ta = 1 mm

Young's Modulus of Adherend, E = 2.1*105 MPa

Poisson's Ratio of Adherend, μ = 0.3

Shear Modulus of Adherend, Ga = 7 MPa

Applied Force,

F = T/R

F= 850000/100

F = 8500 N

Load per unit Width,

P = F/W

= 8500/40

P = 212.5 N

σ = P/t

= 212.5/3

σ = 70.83 MPa

c = L/2

= 150/2

c = 75 mm

u_2 = √ [3*σ*(1 – μ2)/ (2*E*t2)]

u_2= √ [3*70.83*(1 – 0.32)/ (2*2.1*105*32)]

u_2 = 0.00715

u_1 = 2*√2*u2

= 2*√2*0.00715

u_1 = 0.02

k = {cosh(u2*c)*sinh(u1*L) / [cosh(u2*c)*sinh(u1*L) + 2*√2*cosh(u1*L) * sinh(u2*c)]}

={cosh(0.00715*75)*sinh(0.02*150)/[cosh(0.00715*75)*sinh(0.02*150) +2*√2*cosh(0.02*150) *sinh(0.00715*75)]}

= {cosh(0.53625)*sinh(3)/[cosh(0.53625)*sinh(3) + 2*√2*cosh(3)*sinh(0.53625)]}

k = 0.418

Maximum Adhesive Shear Stress,

τ_o,max = (σ/8)*(1 + 3k)*√(8*Ga*t/E*ta)

= (70.83/8)*(1 + 3*0.418)*√ (8*7*3/2.1*105*1)

τ_o max = 3.564 MPa

III.METHODOLOGY

For the dissertation work is proceed in following manner. Analytical treatment using FEA approach and physical experimentation. The raw materials used in this work are

1. Two different types of adhesive epoxy
2. Liner pad
3. Steel shoe plate

For the dissertation work different parameters such as different types of adhesive epoxy, adhesive coat patterning, adhesive joint thickness, base plate different groove pattern and adherent surface treatment are chosen. Effect of all these parameter are analyze in regards of adhesive joint strength for brake shoe application. Whereas for this paper discussion regarding different types of epoxy material for adhesive coat pattern is discuss below.

DISCUSSION FOR BRITTLE ADHESIVE

This paper discuss the analytical result obtain by computational approach for brittle adhesive of brake shoe joint. Comparative study of brittle and ductile adhesive joint is done for different variant for both the adhesive material.

The brittle adhesive when applied on a patterned surface are expected to have different behaviors. The brittle adhesive, Araldite 71 with Hardener is a two component, room temperature curing paste adhesive of high strength. When fully cured the adhesive will have an excellent performance at elevated temperatures (120 ºC) and has high chemical resistance. It is suitable for bonding a wide variety of metals and is widely used in many industrial applications where resistance to aggressive or warm environments is required. The mechanical properties of the adhesive can be seen on Table 2.

Table 2: Mechanical properties of brittle adhesive

Shear modulus G (MPa)	2583
Shear yield stress, τ_{ya} (MPa)	25.0 ± 0.55
Shear strength, τ_r (MPa)	30.2 ± 0.40
Shear failure strain, γ_f (%)	5.5 ± 0.44

ANALYTICAL TREATMENT FOR CASE STUDY

This presents a computational approach for the assessment of the given problem. One of the main features of the work is the search for simplicity and robustness in all steps of the modeling, in order to match the proposed method with industrial practices and constraints. The proposed method utilizes software in the domain of FEA (Finite Element Analysis) for analyzing the effects of the variation in the values of the design parameters influencing the response parameter. For our case, suitable CAE software in the structural domain like Nastran/Ansys/ Abaqus/ RadioSS or similar solver would be deployed.

Steps in analytical treatment for case study: Brake shoe 3D modeling is done in CATIA.

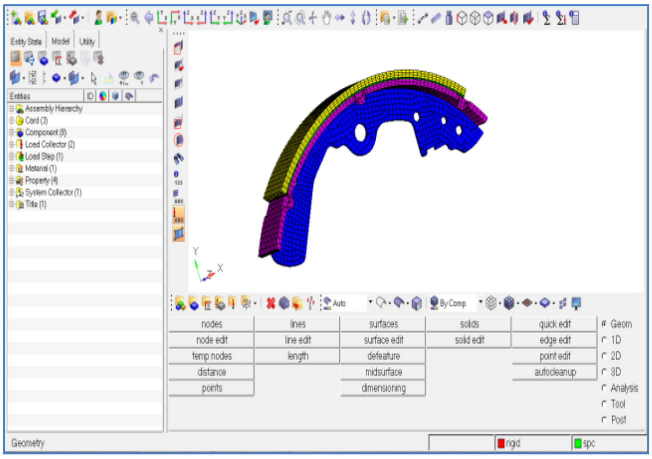


Fig.2 Meshing of brake shoe adhesive joint

Load and Boundary Conditions:

Torque is applied at the centre of the wheel and upper surface of abrasive is constrained to simulate the shear.

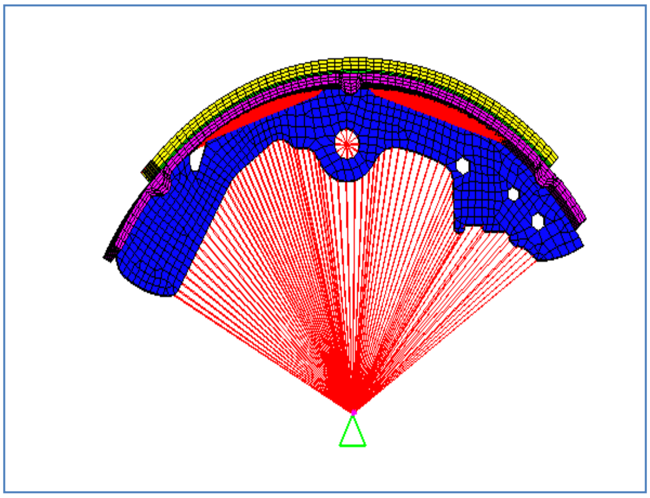


Fig.3 Load and boundary conditions

RESULTS AND DISCUSSION FOR BRITTLE ADHESIVE

By using analytical treatment for case study for all five variants, shear stresses for brittle adhesive joint are observed as given below.

Variant No. 1: Thickness of Adhesive = 3 mm

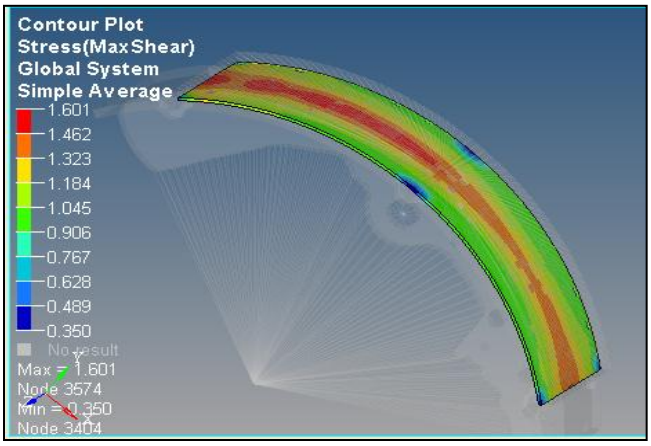


Fig.4 ANSYS shear stress analysis for variant 1

Above Fig.4 shows the shear stress plot for adhesive of thickness 3 mm. Here, we are getting maximum shear stress of 1.601 MPa (τ_o max = 1.601 MPa).

Variant No.2: Thickness of Adhesive = 1.5 mm

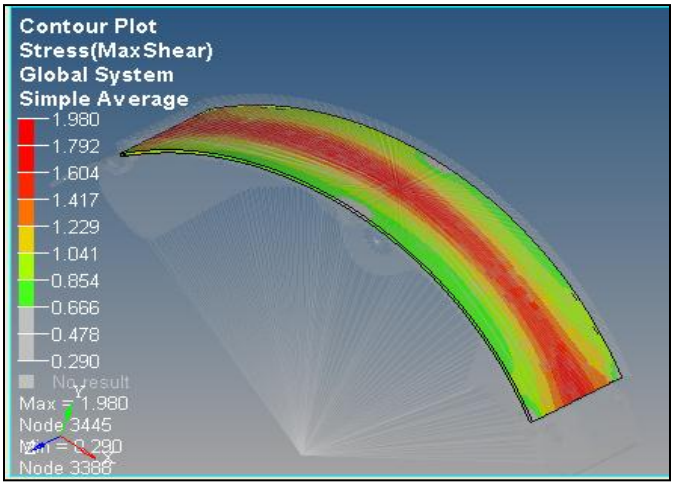


Fig.5 ANSYS shear stress analysis for variant 2

Above Fig.5 shows the shear stress plot for adhesive of thickness 1.5 mm. Here, we are getting maximum shear stress of 1.980 MPa (τ_o max = 1.980 MPa).

Variant No. 3: Adhesive coat is applied as stripes in longitudinal direction

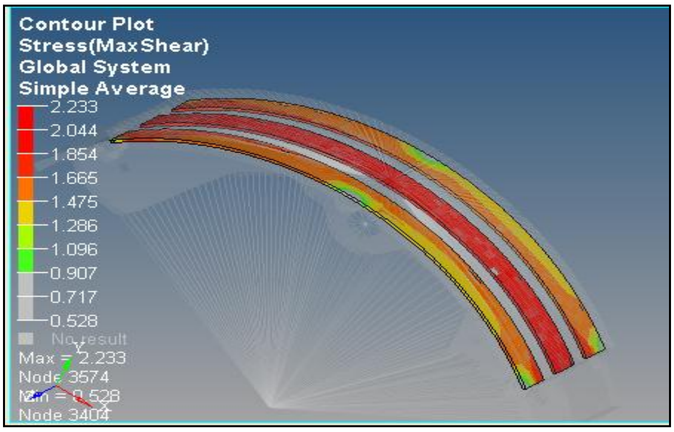


Fig.6 ANSYS shear stress analysis for variant 3

Above Fig.6 shows the shear stress plot for adhesive of thickness 3 mm and adhesive coat is applied as stripes in longitudinal direction. Here, we are getting maximum shear stress of 2.233 MPa (τ_o max = 2.233 MPa).

Variant No. 4: Adhesive coat is applied as checkered stripes

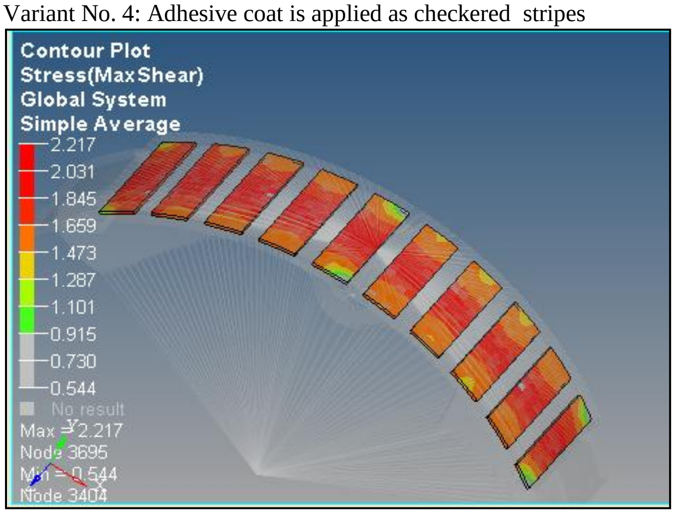


Fig.7 ANSYS shear stress analysis for variant 4

Above Fig.7 shows the shear stress plot for adhesive of thickness 3 mm and Adhesive coat is applied as checkered stripes. Here, we are getting maximum shear stress of 2.217 MPa (τ_o max = 2.217 MPa).

Variant No. 5: Brake shoe adhesive full coat is applied with reduction in lateral dimension

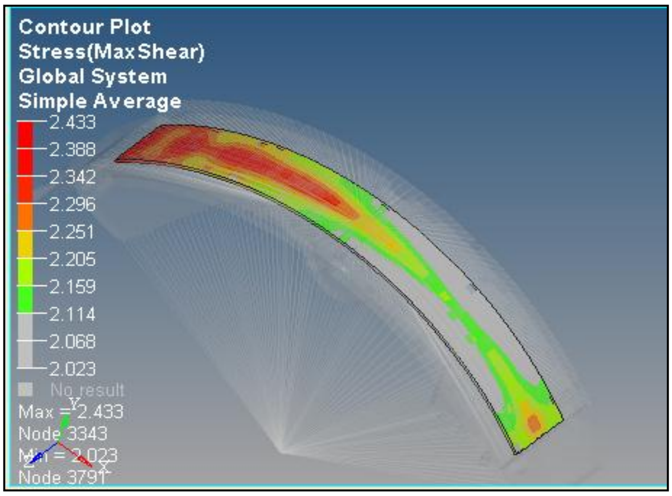


Fig.8 ANSYS shear stress analysis for variant 5

Above Fig.8 shows the shear stress plot for adhesive of thickness 3 mm brake shoe adhesive full coat is applied with reduction in lateral dimension. Here, we are getting maximum shear stress of 2.433 MPa (τ_o max = 2.433 MPa). For above all variant analytical analysis it is found that shear stress obtain for each variant is in permissible limit i.e. 3.564 Mpa noted from mathematical treatment.

IV. MPARATIVE STUDY FOR BRITTLE AND DUCTILE ADHESIVE JOINTS:

A. Comparative study of brake shoe joint with different adhesive layer material:

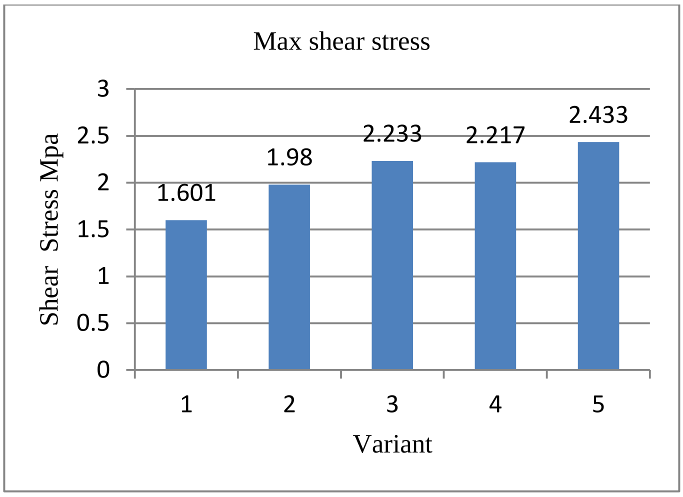


Fig.9 Comparative study of shear stress (MPa) max in brake shoe joint with brittle adhesive layer:

The analysis result obtain for brake shoe joint with brittle adhesive material for different variant are summarized in fig.9. It shows that the entire variant chosen for brittle adhesive for shear strength of joint are within permissible limits. For ductile adhesive same brake shoe variant are analyze as like brittle adhesive. The analysis is carried out for all five variant and shear stress obtain for all five variant are discuss in fig. For the both type of adhesive material analyze using computational approach it is found that both adhesive material joint are within permissible limit of strength. Thus any of adhesive material and a variant can be chosen for application based on feasibility of manufacturing

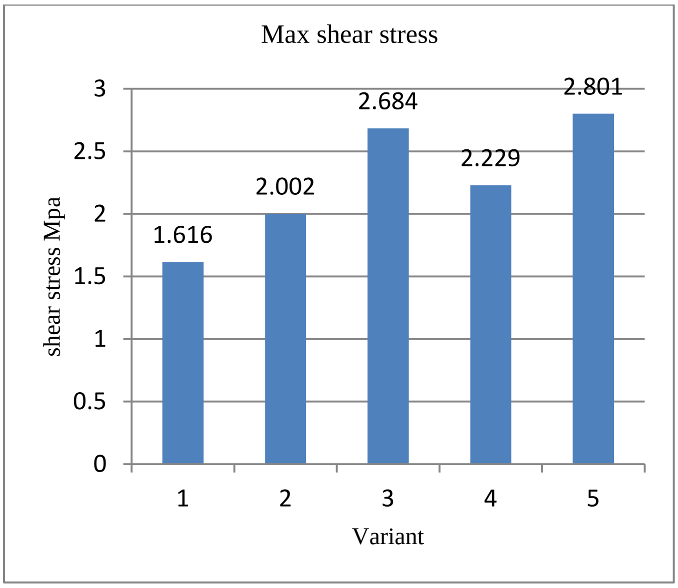


Fig.10 Comparative study of shear stress (MPa) max in brake shoe joint with ductile adhesive layer:

B. Outcomes of FEA analysis:

The results for the five different variants evolved during the study assert the significance of the parameters determined for this work. The parameters for thickness of the adhesive and the area of contact are best manifested in the variant. Other suboptimal variants can also be considered for use based upon the discretion of the design engineer. The stress distribution observed over the interface of the brake pad suggests non – uniform distribution of stresses. The side (end) of the brake pad exposed to the torque exerted by the moving brake disc experiences the highest stress levels; (although the permissible limit of shear stresses has not been exceeded at any point as per the analytical results). In next section the validation of result was done by experimental analysis.

V. EXPERIMENTAL ANALYSIS OF BRAKE SHOE AHESIVE JOINT

The main problem to be analyzed in this paper is estimation of strength evaluation of adhesive joint in brake shoe of an automotive system response to mechanical loading.

A. TESTING FOR SHEAR UNDER TENSILE LOADING:

The experimental research was carried out. Investigation for existing benchmark configuration for adhesive material carried out. For shear testing is performed to determine the shear strength of a material. It measures the maximum shear stress that may be sustained before a material will rupture. Shear is typically reported as MPa (psi) based on the area of the sheared edge. Shear testing is commonly used with adhesives and can be used in either a tensile or comprehensive their mechanical properties with corresponding joints.

B. EXPERIMENTAL RESULT:

In order to draw confident conclusions regarding the strength evaluation of adhesive joint in brake shoe of an automotive system a comparison between the experimental result and FEA analysis result is presented in the following. The experimental results concerning the adhesive joint in brake shoe were presented.

For existing benchmark geometry with 3mm thk of adhesive joint and brittle adhesive material, there is 0.03% and 1.59% of variation in displacement and shear stress respectively. Also existing benchmark geometry is tested for displacement and shear stress respectively. The physical experimentation for shear stress is within the permissible shear stress limits of 3.564 MPa. Thus all other variant having analytical results within the permissible limit of shear strength can be adopted for practical application.

VI. CONCLUSIONS

- The recommended variant needs to be implemented in practice. This might pose several problems in terms of designing a dispenser for releasing the adhesive over the designated mating area of the brake shoe and the brake pad. Further research work could be taken up in this area (for implementation).
- Varying grades and brands of adhesives could be put to test for evolving improved variants, other than proposed in this research work. Thickness could be varied as also the configuration of the pattern of application.
- Texture/Surface finish/Surface treatment can be explored as additional parameter while pursuing further studies. Curing temperature and curing time could also be tweaked while seeking optimization over the influencing factors.
- This study could be replicated in similar other areas of application in the consumer products or the aerospace industry.

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