Assessing Geometry of the Adhesive Pattern for A brake Shoe Joint to Minimize Mass of the Adhesive

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Abstract— The adhesive joint for the disc brake is the subject of study for this dissertation work. The brake system is expected to endure the shear forces during braking at the operating speed of the vehicle. The adhesive joint is analyzed using computational tool in the CAE domain - HYPERWORKS. The virtual model for the brake shoe joint consist of the base, the liner and the adhesive layer keeping the mating parts in place. Pre-processing for analysis carried out using HYPERMESH while generating suitable mesh and assigning the loads and boundary conditions for the Finite Element Model. The FE model solved using OPTISTRUCT followed by post-processing using HyperView. The geometry or the configuration of the adhesive layer altered to investigate four variants – Horizontal stripes, vertical stripes, inclined strips and criss-cross stripes. The results are reviewed with a plan for experimentation for the suitable variant. Realizing the objective of using minimal adhesive to perform the intended function is the focus of this work. The design parameter for this work has been identified as the `Geometry' of the adhesive layer. A researcher could consider pursuing future work over `Material' as a parameter for study. The work has used `Altair HYPERWORKS as a computational tool (solver) while determining the solution. Alternative solvers like ANSYS or NASTRAN could be considered for deployment. A doctoral program might consider theme as `multi-parameter/multi-response optimization' for the adhesive joint using Statistical Treatment to the experimental data.

Key words: Brake Shoe, Brake Liner, Adhesive Joint, Computational Methodology, Pattern, Shear Strength

I. INTRODUCTION

An adhesive has a great importance in composite materials and their applications. It is any substance applied to the surfaces of materials that binds them together and resists separation. The term "adhesive" is also called as glue, cement, mucilage, or paste. Application of adhesive depends upon the type of materials joined, or conditions under which it is applied. High shear strength, Short curing time, High peel strength, Good environmental resistance these are more important features of an adhesive. This research paper is focus on strength of adhesive of brake shoe. Disc brake shoe is subject for this work, which is consists of linear base brake pad and an adhesive material. Where linear base is made up of steel (EN 31). For adhesive Loctite is used. 5 variants are created having different pattern of adhesive surface i.e. vertical, horizontal, inclined and criss-cross. Three different methods area used for analysis purpose, i.e. analytical, mathematical and experimental method. After manufacturing of brake shoe of disc brake, linear static analysis is carried out by using HYPERMESH and OPTISTRUCT software. Structural analysis is application of the finite element method. The term structural means not only bridges and buildings, but also aeronautical, and mechanical structures such as ship hulls, aircraft bodies, and machine housings, as well as mechanical components such as pistons, machine parts, and tools. Structural analysis is the finding out effects force on structures and their components. In mathematical method braking force is calculated at speed 80km/h of vehicle. After getting the results from finite element analysis experimentation is conducted for validation of results.

Fig. 1: Disc Brake shoe

II. LITERATURE REVIEW

Neha B Thakre, A B Dhumne-The need to design lightweight structures and the increased use of lightweight materials in industrial fields, have led to wide use of adhesive bonding. Recent work relating to finite element analysis of adhesively bonded joints is reviewed in this paper, in terms of static loading analysis, fatigue loading analysis and dynamic characteristics of the adhesively bonded joints. In this work fabrication of joint using Ms flat plate will be done. The joint will be made by welding, riveting and adhesive bonding process. Adhesive bond will be created by using epoxy as an adhesive material. The numerical calculation will be done for the experimental analysis. Computational analysis will be comprising of stress, buckling and vibrational analysis. Result of experimental analysis will be validating withcomputational analysis. [1]

Prashant Sudhiranjan Rade, 2Prof. Dr. Dheeraj S. Deshmukh, 3Swapnil S. Kulkarni -This dissertation work is aimed to investigate the adhesive joint shear strength for a braking system. The problem is investigated using mathematical analysis as well as analytical methodology with Finite Element Analysis. The dissertationhas is presented with variants of different adhesive layer thickness proposed for the shear strength investigation of adhesivejoint to be used in the automotive industry. In FEA, the competent software 'NASTRAN' is used for determining the shearstress induced in different thickness of adhesive layer applied between brake pad and brake shoe. Comparative study for themethodologies is presented while arriving at the most suitable variant of the brake shoe with respect to the thickness of theadhesive layer and the geometry manifested by the pattern of the adhesive layer applied. A total of five variants withdifferent adhesive layer thickness are analysed for concluding the thesis work. [2]

Mamhood Hasan Dakhil1, A. K. Rai2, P. Ravinder Reddy3 & Ahmed Abdulahsen Jabber4-This paper presents optimized design of performance of disc brake using finite element analysis is to evaluate theperformance under severe braking conditions. Cast iron and stainlesssteel are used as disc brake materials. ANSYS 12.0 isa dedicated Finite element package used for determining the temperature distribution, variation of stresses and deformationacross the disc brake. It has been made to investigate the effect of the temperature distribution with the deformed shape andstress distribution of disc brake rotor design by usingdifferent braking conditions. From the results of the above data, theservice life and long term stability is ensured. A steadystatic structureanalysis has been carried out to investigate thetemperature variation across the disc using the axis symmetric finite elements. Further structural analysis is also carried outby Coupled Field Analysis. An attempt is also made to suggest a best combustion of material, flangewidth andwallthickness used for disc brake rotor, which yields a low temperature variation across the rotor, less deformation andminimum Von-misses stress possible. [3]

Debora C Moreira and Luiz CS Nunes-Flexible adhesives play an important role in various applications. The possibility ofbonding dissimilar substrates has generated wide interest in flexible adhesives.However, most of the theoretical and experimental investigations have focused onrigid epoxy adhesives. The purpose of this work is to investigate the mechanicalbehaviour of a flexible adhesive joint in the overlap region. Aluminium adherentswere used for single lap joint made with an adhesive characterized by high flexibilityand large strains. The specimen was tested in tension. Full-field displacements of theoverlap region were measured by the Digital Image Correlation method. A largeshear strain of the order of 48% was observed. Small transverse deflections of theadherents were estimated. Also, it was observed that the shear strain distribution inthe adhesive layer decreases at the overlap ends, which is different from previouslyreported results in the literature.[4]

Er. N. B. Shinde1, Prof. B.R. Borkar2 -The aim of my paper is to show how to perform a crashworthiness simulation in the automobile industry using Finite Element Method, Repetitive braking of the vehicle leads to heat generation during each braking event. The resulting rise in temperatures have very significant role in the performance of the braking system. Problems such as premature wear of brake pads and thermal cracking of brake discs are attributed to high temperatures. Consequently, controlling the temperature profiles and thermo-mechanical stresses are critical to proper functioning of the braking system. CAE simulations are often used for evaluating the brake disc design using thermo-mechanical analysis techniques. Conventional approach is to use three-dimensional FE models of the brake discs. This approach has major drawbacks of higher pre and post processing as well as solution times. Need is felt to develop a quick and reliable method to evaluate the thermal stresses in brake discs. This paper describes one such approach based on modified FEM axisymmetric analysis. This paper reviews numerical methods and analysis procedures used in the study of automotive disc brake. It covers Finite Element Method approaches in the automotive industry, the complex Contact analysis. The advantages and limitations of each approach will examine. This review can help analysts to choose right methods and make decisions on new areas of method development. It points out some outstanding issues in modelling and analysis of disc brake squeal and proposes new conceptual design of the disk braking system. It is found that the complex Contact analysis is still the approach favored by the automotive industry. Investigated the effects of the rotating speed ofthe disk and the material properties on wear behaviors. To reduce the solution time for the problem inFEA by utilizing ANSYS's contemporary advantages incontact and thermo-mechanical problems. [5]

NunzianteValoroso1 and Silvio de Barros2-The cohesive zone approach has gained increasing success in recent years for simulating deboning and fracture via finite element methods and is ideally suited for simulating adhesive joints, the potential crack paths being generally known in advance in most cases. In the paper the determination of the size of the so-called cohesive process zone is discussed, i.e. the region wherein the stress and damage state have to be correctly resolved in order to properly quantify the dissipated energy and the load bearing capacity of the structure. An a priori estimate for the size of the active process zone is provided based on the beam on elastic foundation model in which the material parameters of the cohesive law are incorporated.The formulation of the cohesive model in a damage mechanics format is first provided. The beam on elastic foundation model is then recalled and an approximate solution for the cohesive zone length is found that depends on a material length and a geometric parameter as well. Numerical results are presented for Double Cantilever Beam (DCB) geometry with varying thickness for which bilinear and exponential cohesive laws are considered. The influences of the geometry and of the shape of the cohesive law are put forward in terms of global response and evolution of the cohesive process zone. The size of the process zone is found to be quite sensitive to the specimen characteristic size, whose influence is well captured even using a simplified modeling wherein the original cohesive law is changed into an ideal perfectly brittle one. This leads to fairly good estimates of the size of the cohesive zone compared tofinite element results. [6]

S. S. Kurennov, A. G. Koshevoi, and A. G. Polyakov-The adhesive joint Goland and Reissner model was generalized for the arbitrary number of the adherent layers. This model was used for the stress state analysis in the layered composite rod with metal edging. Thus, the study performed shows that the joint destruction can occur in the form of composite material exfoliation along the connective layers, nearest to the adhesive layer. The technique proposed is not sensible to the packet thickness over joint length ratio, in contrast to the classic beam theory. This technique can be used for computation of the construction part joints of the layered composite materials with the stepped joint thickness change, the load-bearing element joints.[7]

V. M. Popov- A technology of polymer adhesive modification is suggested for adhesives used in aircraft structures bonding. The technology is based on exposure of polymer component melt of the adhesive to an electric and wave field. A decrease of internal stresses and increase of the strength of adhesive joints based on modified adhesives are experimentally established. Electron microscopic and X-ray structural analyses indicated the mechanism of strength enhancement of adhesive joints based on modified adhesives due to adjustment of their structure on the nanoscale level. The results of studies presented provide reasons for the statement that the suggested way of modification of polymer adhesives, being used to bond aircraft metal parts, allows development of high strength adhesive joints. This technology may be practically realized both in adhesive production industry and directly in aircraft production industry. [8]

Antonino Valenza & Vincenzo Fiore & LivanFratini - In this paper, the influence of several parameters on the mechanical behavior and failure modes of hybrid bonded joints aluminum/composite was investigated. Particularly, the effects of metallic surface condition, adhesive properties and thickness on single-lap joint resistance were analyzed. To these aims, two adhesives were used and, for each adhesive, two different adhesive thicknesses (0.5 and1.5 mm) have been investigated. Furthermore, two sets of joints for each adhesive kind and thickness were investigated: the former was obtained using aluminum blanks, which were previously mechanically treated with sandpaper (P60) and the latter using aluminum treated with sandpaper and with presence of fillets in the ends of the overlap area. As regard the thickness of the adhesive layer, the better value is found to be equal to0.5 mm, for both adhesives investigated. [9]

Yu Zhang1, Tai Yan Qin2, Nao Aki Noda3 and Meng Lan Duan1-Nowadays, adhesive joints are widely used in riser pipes, which are subjected to many kinds of loadings in deep sea, such as external pressure, internal pressure, tension, torsion, bending, and also a combination of these loadings. Adhesive joints of riser pipes are the most dangerous parts in term of strength, as singular stress fields exist at the end of the interface between the adhesive and the adherents, so itis very important to evaluate the strength of adhesive bonded joints for riser pipes in deep sea environment loadings. In this research, the strength of adhesive joints of riser pipes is studied under external pressure, internal pressure, tension, torsion, bending loadings, and it is found that singular stress fields exist around the end of the interface. The riser pipe under external pressure, internal pressure and tension loading is more prone to break than under bending and torque loading. In this paper, a 3D adhesive joint model was constructed using FEM, and the singular stress field around the end of the interface between the adhesive and the adherent was analyzed for cases of external pressure, internal pressure, tension, bending and torque loadings. [10]

Guoshun Wang and Rong Fu - Utilizing ABAQUS finite element software, the study established the relationship between a brake pad structure and distributions of temperature and thermal stress on brake disc. By introducing radial structure factor and circular structure factor concepts, the research characterized the effect of friction block radial and circumferential arrangement on temperature field of the brake disc. A method was proposed for improving heat flow distribution of the brake disc through optimizing the position of the friction block of the brake pad. Structure optimization was conducted on brake pads composed of 5 or 7 circular friction blocks. The result shows that, with the same overall contact area of friction pair, an appropriate brake pad structure can make the friction energy distribute evenly and therefore lowers peak temperature and stress of the brake disc. Compared with a brake pad of 7 friction blocks, an optimized brake pad of 5 friction blocks lowered the peak temperature of the corresponding brake disc by 4.9% and reduced the highest stress by 10.7%. [11]

III. PROBLEM DEFINITION

The brake shoe joint while being resistant to shear forces may also address the aspect of economy. Prima facie, the quantity of adhesive per unit might seem negligible since only a few grams of adhesive needs to be applied for effecting a secure joint. The perception, although, is not the same when a couple of thousand units need to be manufactured in a week for a given variant of automotive. Any research in this area could translate into savings for all the models using similar method of joining. Considering the industry, in general, the findings could help validate the application while ensuring justified use of the high-cost adhesive material. Besides, excessive use of the adhesive may adversely affect the structural strength of the joint. Linear stripes in the horizontal and vertical directions and criss-cross pattern investigated and analyzed for possible effective configuration of the orientation of the stripe. During this research work, the joint ensured to address the criteria of the permissible shear strength for the given adhesive. The Parameters - type of adhesive, thickness of the layer and the extreme boundaries covered remains constant throughout the research work. The parameter to be varied for this work is the geometry (or the configuration of the pattern) of the adhesive layer. The benchmark geometry being a continuous plain layer of uniform thickness extending throughout the inner region up to the boundary of the mating part i.e. the brake shoe liner. The adhesive layer is applied over the top surface of the base, typically, a metallic sheet or plate. The bottom face of the liner pasted over this adhesive layer and allowed to cure at room temperature while being clamped in a vice with a pre-determined force for a given time. Mathematical treatment offered in the initial phase of the work.

Accelerometer are available to detect magnitude and direction of the proper acceleration that could be in either of X Y Z direction (or g-force), as a vector quantity, and can be used to sense orientation (because direction of weight changes), coordinate acceleration (so long as it produces g-force or a change in g-force), vibration, shock, and falling in a resistive medium (a case where the proper acceleration changes, since it starts at zero, then increases).

IV. METHODOLOGY

Three different methods are used for linear static analysis of brake shoe.

1) Analytical method

2) Mathematical method
3) Experimental method

For analysis purpose, the model is imported to HYPERMESH 11.0 in STEP format and further cleaning process is carried out on the model. Meshing and boundary conditions are applied using HYPERMESH 11.0 as a pre-processor. For static solving purpose typically OPTISTRUCT is used. Results would be predicted using HYPERVIEW 11.0 Software.

For mathematical method brake shoe being a complex geometry with multiple connections we can calculate stress i.e. load v/s displacement simplifying the geometry. This is an approximation process as the complex geometry is simplified.

Experimental method deployed as a methodology for validating the results achieved from analytical method. The static analysis results determined by analytical methodology are validated with the results achieved from physical experimentation. For the experimentation purpose Universal Testing Machine is used and special fixture is manufactured to hold the component on the machine.

V. MATERIAL PROPERTIES

There are serval materials used for adhesive of brake shoe such as epoxy resin, Loctite, aldehyde. Loctite are most demanding material for this application. Loctite 9309 material is used for manufacturing of brake shoe.

A. Liner Base

Material –EN 31
E = $2.15x10^5 N/mm^2$
Poisson Ratio = 0.3
Density = $7.8x10^{-9} tonn/mm^3$

B. Adhesive

MATERIAL-loctite
E=2303 N/mm^2
POISSIONS RATIO = 0.36
Density = $1.15x10^{-9} tonn/mm^3$

C. Pad

MATERIAL- Cu-Sn-Ti Alloy
E = $1.21x10^5$ N/mm^2
POISSIONS RATIO = 0.36
Density = $8.85x10^{-9} tonn/mm^3$

VI. PREPROCESSING OF BRAKE SHOE

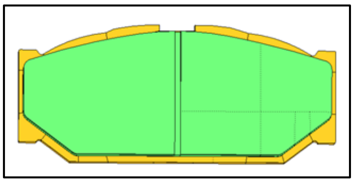

Fig. 2: Brake Shoe Assembly

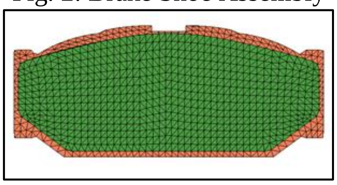

Fig. 3: Meshing of brake shoe

The finite element analysis is numerical method for solving Engineering problems. Linear static analysis for brake shoe is carried out by using OPTISTRUCT software. For this first created 3D model in CATIA, then it goes for meshing by using HYPERMESH 11. Results comes from linear static analysis for variants are shown below.

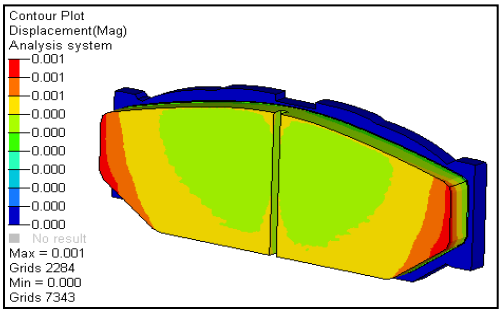

Fig. 4: Displacement contour of benchmark geometry

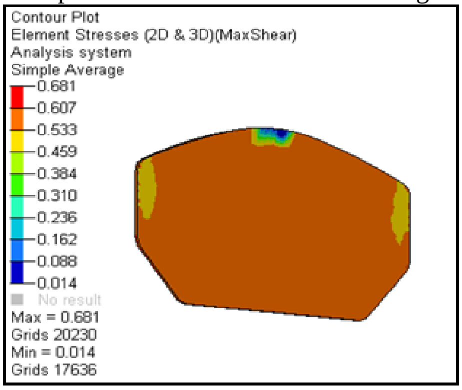

Fig. 5: Stress contour of adhesive of benchmark geometry

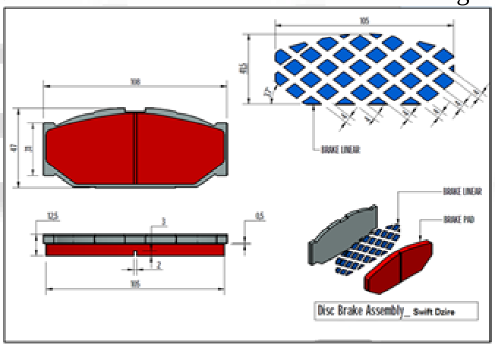

Fig. 6: brake shoe assembly of variant

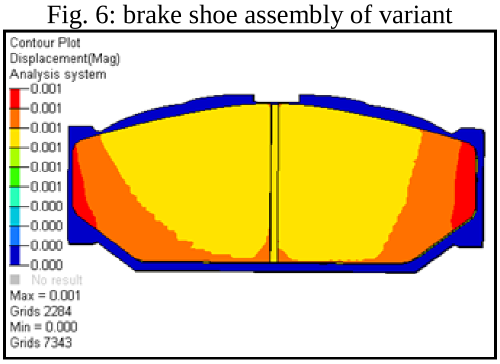

Fig. 7: Displacement contour of variant

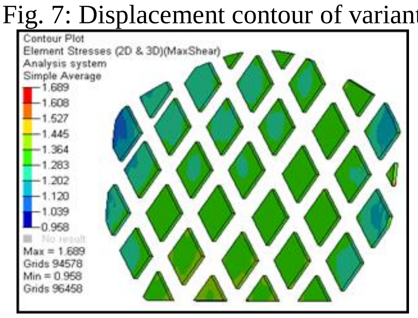

Fig. 8: Stress contour of adhesive of final variant

VII. EXPERIMENTAL ANALYSIS

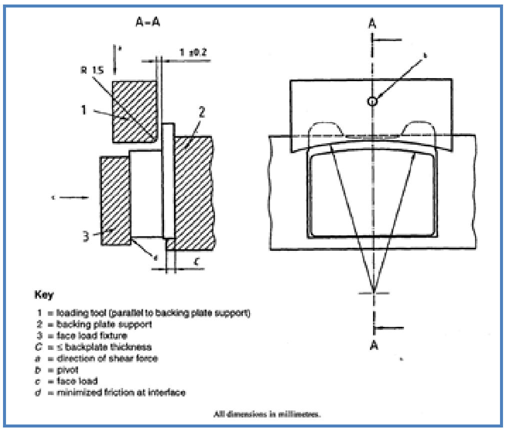

Fig. 9: Experimental Analysis

The component produced for the experimentation is given by the company, which is used for the testing. The input conditions are recreated in the lab while the component is being tested for performance. For simplicity, a Universal Testing Machine along with a suitable fixture for the component engaged for testing purposes. The load applied is 12348N which is the maximum load.

Special Fixture is designed to hold the component for doing the static Analysis. Universal Testing Machine (UTM) machine is used to do the static Analysis. Output received from the experimental setup. The results from the experimental are used for validation with the Analytical results.

VIII. WORK INSTRUCTION

1) Switch ON DC SCIVO control Mains and Digital Shear Controller
2) Select type of Load cell (50, 1000 or 10000 Kg) / Strain gauge extensometer (If required)
3) Switch ON Computer and select appropriate Test from software.
4) Check the initial grip distance and enter required distance.
5) Initialize the machine.
6) Select speed. Strain gauge and other required parameters (refer manual/ standard).
7) Start the test and after test results will display on computer.
8) Exit from software. Switch off DC control Mains and digital shear Controller.


Fig. 10: Universal Testing Machine

IX. ANALYSIS USING FEA

Fig 11 shows the boundary conditions for the experimentation purpose. Due to complex geometry of the component load is applied only on the brake shoe. The complete assembly of the component and fixture is loaded in the UTM for carrying out the experimentation

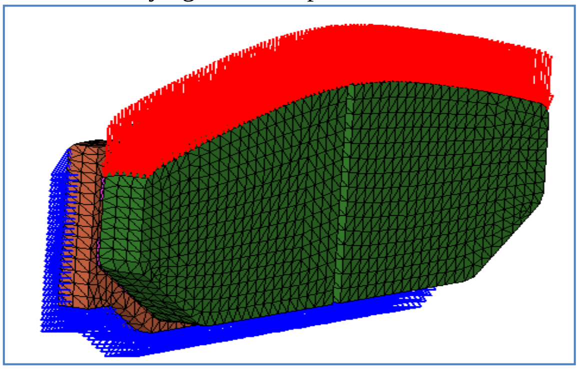
Fig. 11: Loading and boundary condition of best variant

For validating experimental results analysis is carried out for applying load on brake shoe as shown in figure. Fig 11 shows the loading and boundary condition details

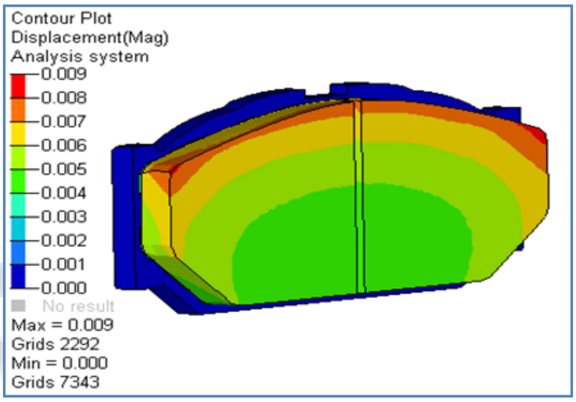

Fig. 12: Displacement plot for load on brake shoe

Fig 12 shows result plot for maximum and minimum displacement locations which are generated in the brake shoe. Max displacement in brake shoe is 0.009mm

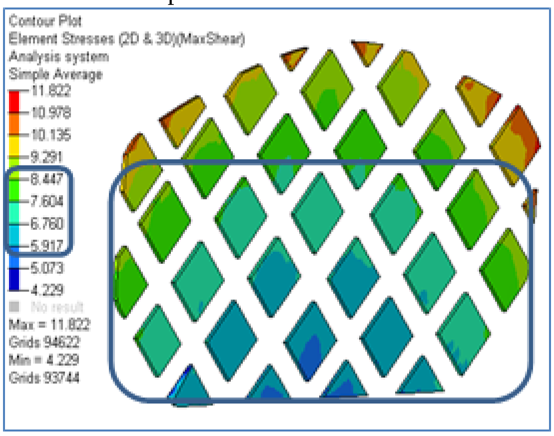

Fig. 13: stress contour for load on brake shoe

Fig 13 shows result plot for maximum and minimum stress locations, which are generated in the brake shoe. The maximum stress zone is observed in the range 8.447 to 5.917 N/mm^2

Shear Stress in Adhesive Test variant (checkered layer) - analytical approach

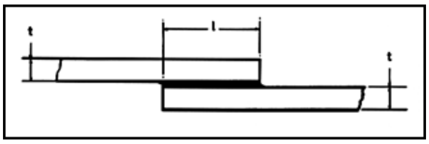

Fig. 14: Simple lap shear joint

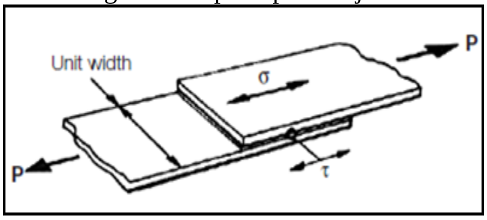

Fig. 15: Conventional designs for stresses in a lap joint

τ = mean shear stress in the joint = P/I
P = load per unit width of joint
I = Optimum overlap
=12348/ (2000)
=6.17 N/mm^2(Mean Stress)

X. Validation

1) FEA results gives variant with least amount of Adhesive layer mass - finalVariant, with a percent mass reduction of about 58.43%, as the recommended variant among the alternatives.
2) The stress levels observed in FEA about 11.822 MPain final Variant is well within the permissible yield limit of 22Mpa with uniform stress distribution.
3) From experiment 12348 N maximum load is observed which applied to brake shoe analytically, stress of 6.18 N/mm^2 calculated which is approximate same in both analyses. it is clear that brake shoe is safe under these condition
4) Experiment results confirms to the stress levels within permissible yield limit indicating the final Variant can be recommended for commercialization.

XI. Conclusion

- Brake pad is analysed under Shear load applied by the Disc.
- Max Displacement Observed - 0.001 mm
- Max shear stress observed - 0.681 MPa (yield 22 MPa).
- Stresses are below yield limit
- Scope for `binder mass reduction' identified for this work.

XII. Future scope

1) The design parameter for this work has been identified as the `Geometry' of the adhesive layer. A researcher could consider pursuing future work over `Material' as a parameter for study
2) The work has used `Altair HyperWorks' as a computational tool (solver) while determining the solution. Alternative solvers like ANSYS or NASTRAN could be considered for deployment
3) A doctoral program might consider theme as `multi-parameter / multi-response optimization' for the adhesive joint using Statistical Treatment to the experimental data
4) The research work pursued was limited to static analysis considering normal driving conditions (80 km/hr). Abuse load conditions could be considered for analysis further involving dynamic loads or such other conditions.

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