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Modelling of Crack Growth in Composite Joints

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ABSTRACT

Adhesive bonding is a technique that involves the solidification or hardening of a non-metallic adhesive material that is sandwiched between the components faying surfaces.The overlap length (Lo) is one of the most critical factors that affect the joint strength. In this project numerical modelling of crack growth in composite joints has been attempted. For this purpose, two broad type of methods of modelling are used namely cohesive zone modelling (CZM) and ductile damage modelling (DDM). All the numerical simulations are performed using ABAQUS. Among other parameters, the interfacial fracture energy has a significant impact on the bond strength (or ultimate load) of such bonded joints. Fracture parameters of HY4080 adhesive for modelling through CZM has been identified through inverse analysis, which can be used for several applications of bonded composite joints including in aerospace and construction. The strength obtained for the 40mm width specimen is high enough to cause yielding of steel plates in the experiment. Further strength can be achieved through special surface preparation methods such as etching or grit blasting. This could further increase the use of these adhesive joints. DDM method has the capability to handle adhesives under different rate of loadings or strains. The method also is able to handle ductile adhesives through plastic property definitions. However, the failure criteria does not account for mixed mode fracture. Hence, there needs further study in understanding how mixed mode fracture can be studied using this versatile method. It can be concluded that CZM is an accurate tool for predicting the strength of bonded joints. The method using the interface interaction is easy to implement. The method using the COH2D4 elements is slightly tedious since it involves more number of elements to model the interface (i.e., the adhesive is modelled as a solid block in-between the plates). However, the effect of thickness can be naturally accounted in this method since the adhesives is modelled with thickness. Both ways are found to accurate. Further the methodology in this thesis is generalised and can be extended for cyclic loading and impact loading as well.

Keywords:-Bonded joints, Cohesive zone models, Ductile damage model, Structural adhesive: Aluminum alloy, Araldite 2015, HY4080,

I. INTRODUCTION

Adhesive bonding is a technique that involves the solidification or hardening of a non-metallic adhesive material that is sandwiched between the components' faying surfaces. Adhesive bonding of difficult structures that couldn't or wouldn't be simply constructed in one piece, and this constraint is increasing these days. Due to the simplicity of manufacturing, increased strength, and adaptability to link various materials, adhesive joints have largely replaced traditional joining techniques like bolted, welded, or riveted joints. Therefore, adhesive joints are being utilizing continuously many of the industries like aerospace, aeronautics, automotive, marine, and footwear, as well as railroads and civil construction. This adhesive joining technique is frequently employed in the building of intricately designed structures, producing structural connections that may be just as strong as the underlying material.

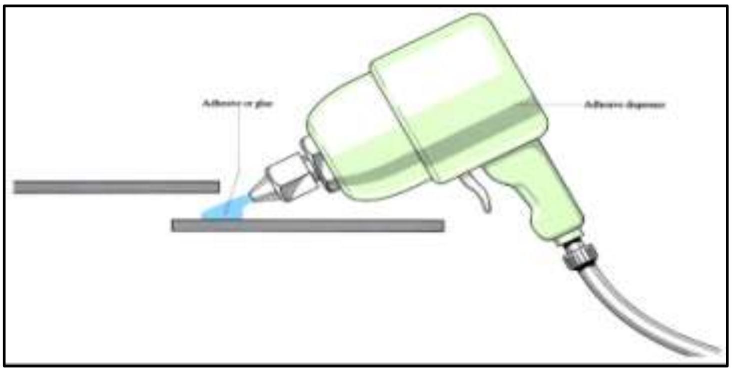

Figure 1.1: Application of glue between two materials [Adhesive bonding, 8th March 2018]

The geometrical requirements, the materials to be joined, and the adhesive characteristics are some of the determining variables in these joints' strength. The overlap length is one of the key factors that significantly influences joint strength (Lo).

1.1 CRACK GROWTH:

Crack growth is the enlarging, extending, or expansion of existing cracks on a particular surface. A crack may develop as a result of the application of additional loads, thermal stressors, stress concentrations, and repeated shrinkage/expansion cycles.

1.2 TYPES OF JOINTS:

The following figure illustrates the many types of joints that may be used to link composite structures, including single lap joints,butt junctions, stepped lap joints,tapered lap joints, scarf joints,strap joints,double strap joints,double lap joints, and tapered double strap joints.

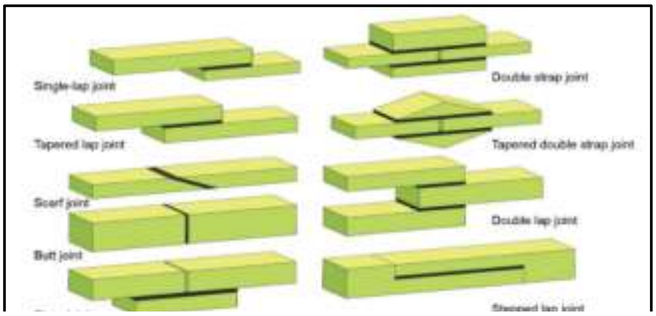

Figure 1.2: Several kinds of adhesively bonded connections [Sanjay Kumar Nayak, 19 Apr 2019]

II. OBJECTIVE OF THE STUDY

The Objective of the research are:

1. Experimental characterization of commercially available adhesive for bonding composites.
2. Development of numerical modelling strategy for strength prediction of composite joints.
3. Calibration of ‘cohesive zone models’ and ‘ductile damage models’ to model adhesives.
4. Parametric study based on calibrated ‘cohesive zone model’ and ‘ductile damage model’.
5. Comparison of numerical and experimental results of ‘cohesive zone model’ and ductile injury model using Abaqus software.

III. SCOPE OF THE WORK

1. Substrates are assumed to be elastic for composites and elasto-plastic for steels.
2. CZM and DDM are used to model damage in the adhesive layer.
3. Quasi-Static conditions are assumed in loading.
4. Effect of triaxiality is considered in DDM while strain rate is not considered.
5. Predominantly shear loaded geometry is considered.
6. ABAQUS is used for simulation.

IV. METHODOLOGY

4.1 IN THIS PROJECT THE TWO METHODS WHICH ARE HAS BEEN USED:

1. Method OfCohesion Zone Model
2. Method Of Ductile Damage Model

4.1.1 COHESION ZONE MODEL METHOD:

The ‘Cohesion Zone Model (CZM)’ is a fracture mechanics model in which crack formation is considered a developing process in which there is fracture surface separation through an expanded 'crack tip' or 'cohesion zone' and is resisted by cohesion forces.

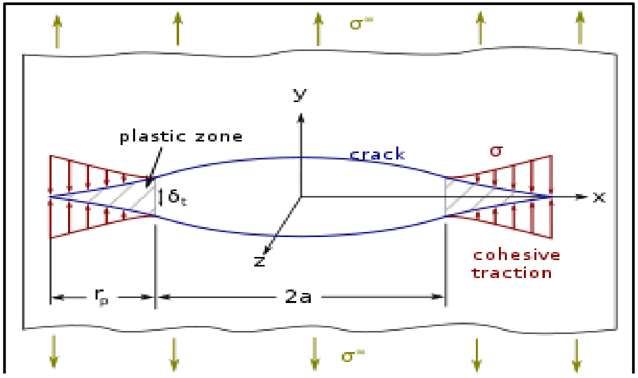

Figure 4.1: Cohesion Zone Model

- **Traction Separation Law:**

The 'cohesion force separation' rule is defined by the interaction between the cohesion force vector and the 'displacement separation vector' acting on the entire interconnected surface. An isotropous material is described by three variable quantity in the form of crucial energy release rate, 'critical tensile cohesive' fracture stress, and traction separation law.

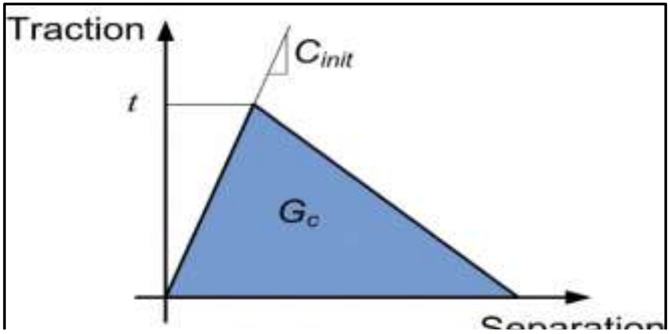

Figure 4.2: Law of traction separation for the Cohesive Zone Method (Gerald Wimmer, November 2006)

4.1.2DUCTILE DAMAGE MODEL METHOD:

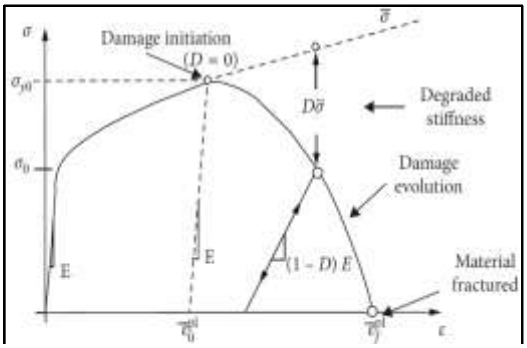

Figure 4.3: The ductile damage model in ABAQUS (Mohammad Abedin, July 2020)

- **Modelling of damage**

An initial elastic deformation under mechanical loads identifies quasi-brittle materials as deforming. A nonlinear fracture phase will follow the elastic phase if a threshold amount of stress or strain is exceeded.

- **Damage Initiation**

Provides material and contact properties to account for the occurrence of damage. This preference is utilized to specify the physical properties that characterize the onset of deterioration.The model for predicting the onset of ductile metal void initiation, growth, and coalescence-related damage is called the ductile injury initiation criterion.

- **Evolution of Ductile Damage**

The ability of ductile metals to withstand damage hypothesises that damage is characterised by a gradual loss of material hardness that eventually results in material failure. In Abaqus FEA there are arrangement alternatives that specify how each 'damage mechanism' affects the whole destruction of the material.

4.1.3 ABAQUS SOFTWARE:

The software package for finite element analysis is called Abaqus. The three main products of 'Abaqus are Abaqus / Standard, Abaqus / Explicit, and Abaqus / CAE'. Using the standard implicit integral approach, the general-purpose solver Abaqus / Standard solves finite element studies. Explicit integration is the method used by 'Abaqus / Explicit' to solve transient dynamics and quasi-static research that is very nonlinear. 'Abaqus / CAE' provides an integrated pre-administering (modelling) and post-administering (visualization) environment for analytical output. 'Abaqus' is used in locomotive, space, and manufacturing applications. It is highly regarded by academic and research institutes for its extensive material modelling capabilities and adaptability.

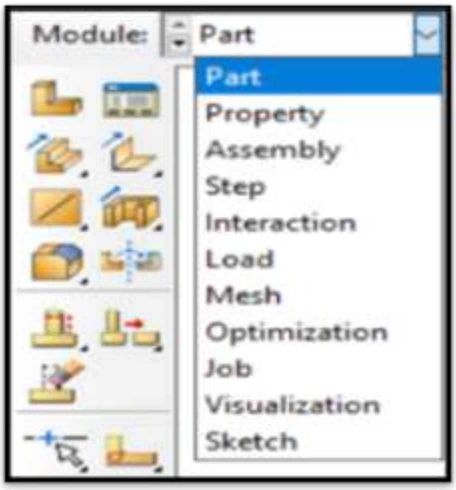

Figure 4.4: Steps in Abaqus

V. METHODS

5.1 MODELLING AND ANALYSIS USING COHESIVE ZONE MODEL THROUGH INTERACTION:-

Table 5.1: CZM specifications for Araldite 2015

Property	Araldite 2015
E (GPa)	1.85
G (GPa)	0.70
t_n^0 (MPa)	21.63
t_s^0 (MPa)	17.9
GIC (N/mm)	0.43
GIIC (N/mm)	4.70

ADHEREND USED: Features of 'AW6082T651 Aluminium Alloy'

Table 5.2: Features of 'AW6082T651 Aluminium Alloy'

Property	AW6082 T651
Young's modulus, E (GPa)	70.07±0.83

Yield stress, σy (Mpa)	261.67±7.65
Tensile strength, σf (Mpa)	324.00±0.16
Tensile failure strain, εf (%)	21.70±4.24

ADHESIVE USED: ARALDITE 2015

Table 5.3: Araldite® 2015 Adhesive Properties

Property	Araldite® 2015
Young's modulus, E (GPa)	1.85±0.21
Poisson's ratio, ν	0.33[a]
Tensile yield stress, σy (MPa)	36.49±2.47
Tensile failure strength, σf (MPa)	39.45±3.18
Tensile failure strain, εf (%)	1.21±0.10
Shear modulus, G (GPa)	1.81[b]
Shear yield stress, τy (MPa)	25.1±0.33
Shear failure strength, τf (MPa)	30.2±0.40
Shear failure strain, γf (%)	7.8±0.7
GIC (N/mm)	0.20[c]
GIIC (N/mm)	0.38[c]

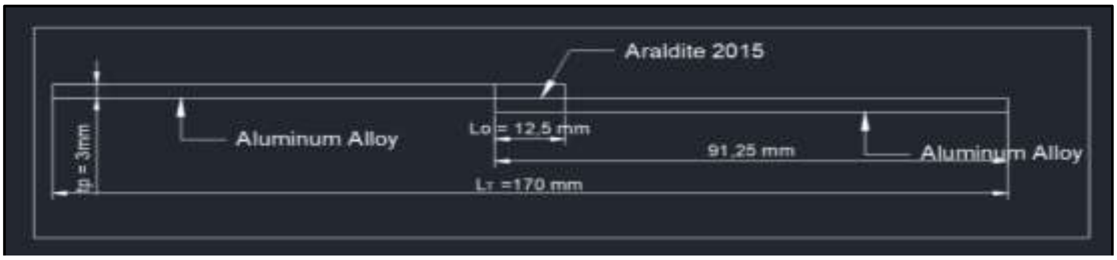

Figure 5.1: Shape and characteristic dimensions of single-layer connection model

DETAILS OF SINGLE LAP JOINT MODELING: The relevant dimensions are bond line thickness (tp) = 3 mm, LO = 12, 25, 37, and 50 mm, and bond length (LT) = 170 mm.

Figure 5.2: Dimensions and specific geometry of the single-lap joint model

Connection Details: Figure 5.2 shows the connection shape. The following characteristic dimensions have been determined (in mm). LT = 240 mm; LO = 20-80 mm; b = 15 mm; tP = 2.4 mm. Four different LO values were examined (20, 40, 60, 80 mm).

ADHEREND USED: FRP COMPOSITE

TABLE 5.4: Properties of the FRP Composite with Elastic Engineering Constants

Ex = 109000 MPa	γ_{xy} = 0.342	Gxy = 4315 MPa
Ey = 8819 MPa	γ_{xz} = 0.342	Gxz = 4315 MPa
Ez = 8819 MPa	γ_{yz} = 0.380	Gyz = 3200 MPa

In these two models such as Numerical modelling of CZM using FRP composites, Araldite 2015 adhesive for various over lap lengths and Numerical modelling of CZM using Aluminium Alloy adherend, Araldite 2015 adhesive the same procedure is followed but except material properties.

5.2 METHOD OF COHESIVE ZONE MODEL THROUGH IMPLIMENTATION OF COHESIVE ELEMENTS USING DIFFERENT THICKNESSES:-

Modelling Details: The pertinent dimensional data are adherend thickness tp = 2.4 mm, various thickness =0.1, 0.3, 0.5, 0.7, 1 mm, and total distance between grabs at the joint LT=240 mm.

ADHESIVE USED: 'ARALDITE 2015_COH2D4'

Table 5.5: Quads damage properties

'Nominal stress' Normal - only mode	'Nominal stress' First direction	'Nominal stress' Second direction
21.63	17.9	17.9

Table 5.6: Destruction Evolution properties

<table>
<tr><td colspan="2">TYPE</td><td>Energy</td></tr>
<tr><td colspan="2">Mixed mode behavior</td><td>Power law</td></tr>
<tr><td colspan="2">Mixed mode ratio</td><td>Energy</td></tr>
<tr><td colspan="2">Power</td><td>1</td></tr>
<tr><td>Destructive energy in 'normal mode'</td><td>Fracture energy first direction in shear mode</td><td>Fracture energy second direction in shear mode</td></tr>
<tr><td>0.43</td><td>4.7</td><td>4.7</td></tr>
</table>

Table 5.7: Damage stabilization cohesive

Viscosity co-efficient	1E-05

Table 5.8: Elastic properties – Traction

E/Enn	G1/Ess	G2/Ett
1850	560	560

5.3 MODELLING AND ANALYSIS USING DUCTILE DAMAGE MODEL:-

Modelling Details: The relevant dimensions are adherend thickness (tp) of 3 mm, (ta) of 0.2 mm, overlap length (LO) of 10, 30, 50, and 80 mm, and total overlap length (LT) of 170 mm.

ADHEREND USED: FRP COMPOSITE

TABLE 5.9: Properties of the FRP Compositewith Elastic Engineering Constants

Ex = 109000 MPa	γ_{xy} = 0.342	Gxy = 4315 MPa
Ey = 8819 MPa	γ_{xz} = 0.342	Gxz = 4315 MPa
Ez = 8819 MPa	γ_{yz} = 0.380	Gyz = 3200 MPa

ADHESIVE USED:ARALDITE® 2015

Table 5.10: Ductile damage properties

Fracture starin	Stress triaxiality	Strain rate
0.8	0.33	1
0.5	1	1
0.439	10	1

Table 5.11: Damage Evolution

TYPE	Energy
Fracture energy	4.7

Table 5.12: Elastic properties – Engineering constants

E1	E2	E3	Nu12	Nu13	Nu23	G12	G13	G23
1850	1850	1850	0.3	0.3	0.3	560	560	560

Table 5.13: Plastic properties – Isotropic

Yield Stress	Plastic strain
14.6	0
17.9	0.439

NUMERICAL MODELING OF DUCTILE DAMAGE MODEL USING ADHEREND FRP WITH ADHESIVEARALDITE 2015 FOR VARIOUS THICKNESS

MODELLING DETAILS:

The necessary dimensional parameters are adherend thickness tp = 3 mm, overlap length (LO) = 80 mm, total length of the connection between grips is LT = 170 mm, and adhesive thickness ta = 0.1, 0.2, 0.3, 0.5, 1 mm.

In these two models such as NumericalmodelingofDDMusingFRPcomposites, Araldite2015adhesiveforvariousoverlaplengths and Numerical modeling of DDM using FRPcomposites, Araldite2015adhesive for various thickness, the same procedure is followed for same properties but different thickness and different overlap lengths.

VI. EXPERIMENTAL INVESTIGATIONS

Evaluation of shear strength of a joint requires strength, fracture toughness parameters for the commercially available adhesives in different modes. These parameters are obtained by carrying out tests on specimen designed to fail under pure mode-I and mode-II conditions. The guidelines for the testing are available in ASTM D1002. In this work only mode-II tests are performed since this is only a preliminary study and mode-II parameters are more important for shear strength of lap joints. Based on the obtained load deformation curve, the appropriate parameters are identified based on the physics of the problem through trial and error.

Fifure 6.1: Tensile test experimental setup**Figure 6.2:**machine-control software

Figure 6.3: Tensile test on steel specimen

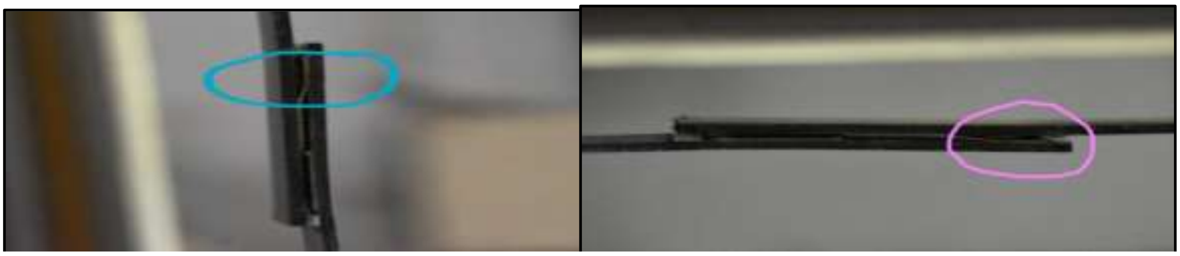

Figure 6.4: The specimen undergoes mild bending changes

6.1 EXPERIMENTAL RESULTS:

The first part of this section gives an overview of the specimen's load-displacement behaviour and failure mechanisms.

Figure 6.5.1: The specimen shown above failed due to cohesion failure

Figure 6.5.2: The specimen shown above failed due to Interlaminar failure of the Steel plate

Figure 6.5.3: The specimen shown above failed due to mutual failure mode including both cohesion failure and Steel interlaminar failure

Figure 6.5.4: The specimen shown in the figure above failed in Mode 1, also known as the Opening mode, in which the fracture starts perpendicular to the crack plane. A bend or pressure application may be the cause of this.

Figure 6.5: Failure modesof test specimen

6.2 NUMERICAL MODELING OF STEEL PLATES WITH ADHESIVE LOCTITE HY4080 FOR VARIOUS OVERLAP LENGTHS:

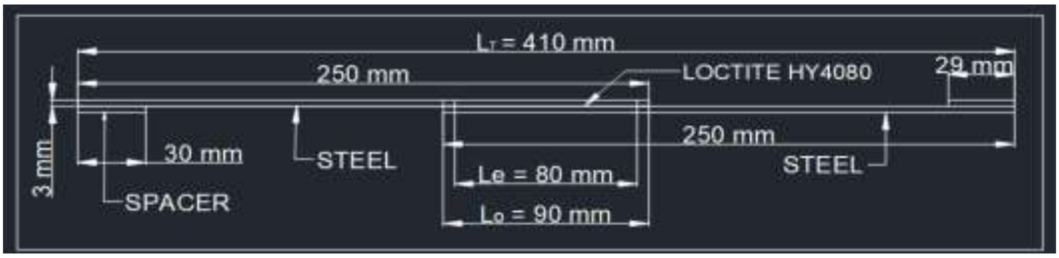

Figure 6.6: Dimensions of the single-lap joint specimen and its geometrical characteristics

THE JOINT GEOMETRIES: The geometry of the joint is shown in Figure 21. The following characteristic measurements were established (in mm):LO = 30 - 90mm; b = 40mm; L_T = 410mm; t_P = 3mm. There were four distinct LO values examined (30, 50, 70, and 90 mm).

<u>ADHESIVE USED</u>: LOCTITE HY4080

LOCTITE® HY 4080 is a two-part hybrid cyanoacrylate/acrylic structural bonding glue that offers excellent adhesion to metals, composites, and plastics as well as durability. Within the first hour, it offers quick installation at room temperature and great operational strength. Over a wide temperature range and in larger gaps, this product maintains good shear strength.

Figure 6.7:LOCTITE HY4080 Adhesive

TABLE 6.1: Properties of the Steel

1) Elastic:

Youngs modulus	Poisson’s ratio
195000	0.3

2) Plastic:

Yield stress	Plastic strain
197	0
350	0.2

TABLE 6.2: Properties of the Adhesive Loctite HY4080

Cohesive behaviour: Specify the stiffness co-efficient

Knn	Kss	Ktt
100	400	400

TABLE 6.3: Damage properties:

Initiation:

Normal only	Shear-1 only	Shear-2 only
5	7.5	7.5

Evolution:

Normal fracture energy	1st shear fracture energy	2nd shear fracture energy
1	4.1	4.1

TABLE 6.4: Geometric properties:

Out of plane surface thickness or cross- sectional area = 40 mm

VII. RESULTS AND DISCUSSION

7.1 COHESIVE ZONE MODEL RESULTS:-

7.1.1 Method Of Interaction:

Comparison Of Numerical Modelling Of Single Lap Joint Model Using Different Adherends For Different Overlap Lengths:-

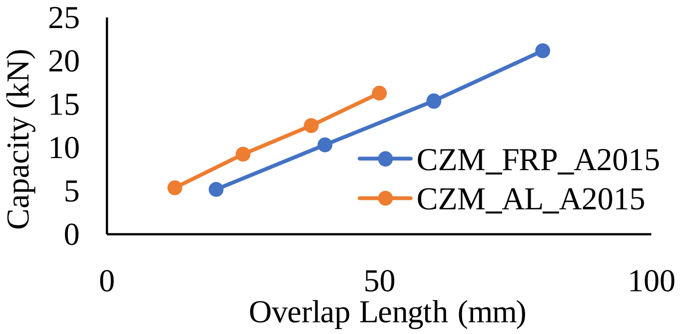

Figure 7.1: Comparison of capacity versus overlap length for various overlap lengths using different adhesives

Finally, compare the numerical modelling of a single lap joint model for different overlap lengths using adhesive A2015, adherend aluminium with the modelling of a single lap joint model using FRP composites, Araldite® 2015 adhesive, which displays that Lo is an significant factor in those models that affects the strength of the joints and plotting the capacity vs overlap lengths graph. In such models, we can see that the capacity grows along with the overlap length, and the suitable factors are found by trial and error based on the physics of the issue. It may be inferred from this that CZM, which utilises Abaqus software, is an precise approach for estimating the strength of bonded connections.

7.1.2.METHOD OF COHESIVE ZONE MODEL THROUGH IMPLIMENTATION OF COHESIVE ELEMENTS [COH2D4] USING DIFFERENT THICKNESS

Table 7.1: The following are the capacities for different thickness of a cohesive zone model using Implementation of cohesive elements.

Thickness (mm)	Capacity (kN)
0.1	6.682545
0.3	7.92087
0.5	6.86331
0.7	5.30995
1	3.389565

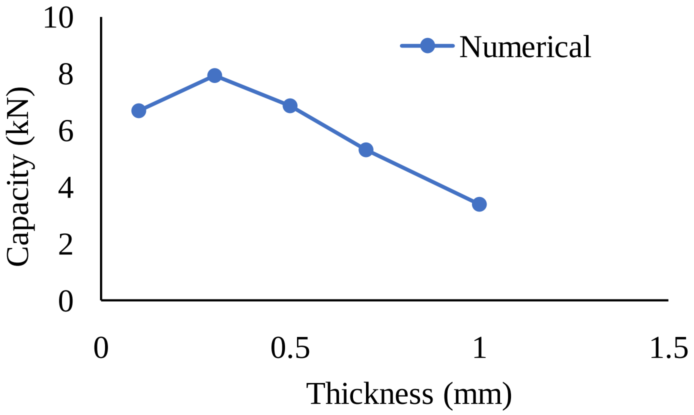

Figure 7.2: Graph of capacity versus thickness for various thickness using CZM method

Finally, compare the numerical modelling of a single lap joint model through implementation of cohesive elements for different thickness using Araldite® 2015_COH2D4, adherend FRP composite. Thickness effects can be taken into account in cohesive components that exhibit traction-separation response by moreover requiring that the original constitutive thickness be calculated from the nodal coordinates of the cohesive components or by specifying a nonzero thickness for the interface. Cohesive constraints are determined at the material locations in cohesive elements. In this model which displays that thickness is an significant factor in those models that affects the strength of the joints and plotting the capacity vs thickness graph. In those models, we can observe that as the thickness increases the capacity gets decreased and the optimum thickness will be 0.3mm. As a result, it can be concluded that finally, the outputs from both methods that is cohesive surface and cohesive element will be nearly same, depending on how we model/meshed the cohesive element. Using Abaqus software, CZM is a reliable approach for estimating the strength of bonded joints.

7.2 METHOD OF DUCTILE DAMAGE MODEL:

7.2.1 Numerical modelling Of A Single Lap Joint Model Using FRP Material And Araldite 2015 For Various Overlap Lengths Using DDMMethod

Table 7.2: The following are the maximum loads for different overlap lengths of a SLJ model

Overlap Length Lo(mm)	Maximum Load Pm (N)	Maximum Load Pm (kN)
10	102.921	1.54382
30	306.98	4.6047
50	501.721	7.52582
80	809.295	12.1394

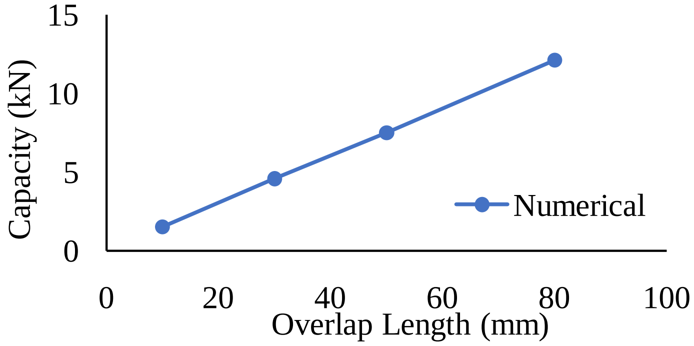

Figure 7.3: Graph of capacity versus overlap length for various overlap lengths

All the four a single lap joint with Adherend FRP material and Araldite 2015 adhesivemodels with the same properties but different overlap lengths are created. In this model the stress triaxiality 0.33, 1, 10 it will fails under fracture starin 0.8, 0.5, 0.439 and strain rate is not consider. Strain rate is the rate of deformation caused by strain in a material over time. This metric measures the rate at which material distances change over time. Finally, the graph of capacity versus overlap length is plotted this is seen in fig. 7.3 and demonstrates that load increases as the overlap duration increases. This indicates that overlap length is an important parameter in this model, and the overlap length is one of the factors most crucial to joint strength (LO).Software called Abaqus is used for this. The DDM is therefore shown to be a trustworthy method for estimating the strength of bonded joints.

7.2.2 Numerical ModelingOf Ductile Damage Model Using Adherend FRP With Adhesive Araldite 2015 For Various Thickness

Table 7.3: The following are the maximum loads for different thickness of a SLJ model

Thickness	Maximum Load (N)	Maximum Load (kN)
1	814.511	12.217665
0.5	805.99	12.08985
0.3	799.509	11.992635
0.2	788.866	11.83299
0.1	755.967	11.339505

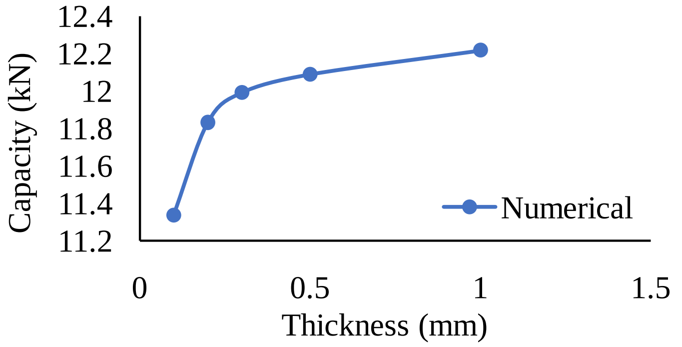

Figure 7.4: Graph of capacity versus thickness for various thicknesses

Based on the DDM method, all five a single lap junction using Adherend FRP material and Araldite 2015 adhesive models with the same qualities but various thicknesses are constructed. The stress triaxiality 0.33, 1, 10 in this model will fail under fracture starin 0.8, 0.5, 0.439 and strain rate is not considered. Strain rate is the rate at which a material deforms due to strain over time. The rate at which material distances vary over time is measured by this metric. In this model Tie constraint is employed in this model because it connects two different surfaces so that there is no relative motion between them. Finally, a capacity versus thickness graph is created, which reveals that as thickness grows, capacity increases, as illustrated in fig 7.4. This implies that thickness is an important component in this model, and thickness is one of the most critical parameters influencing joint strength (ta), which cannot be done using the CZM approach. The presence of significant plastic deformation or necking distinguishes a ductile failure, which happens in malleable materials. Before the material fails, this often happens. Abaqus software is utilized for this. As a consequence, it has been found that the DDM is a trustworthy instrument for determining the strength of bonded joints and for spotting damage failure in adhesively bonded joints.

Experimental Investigations Results:-

7.2.3 LOAD–DISPLACEMENT BEHAVIOR:

Based on the experimental results Fig. 7.5 depicts the specimen's load-displacement curve. The displacements depicted in Fig. 7.6.

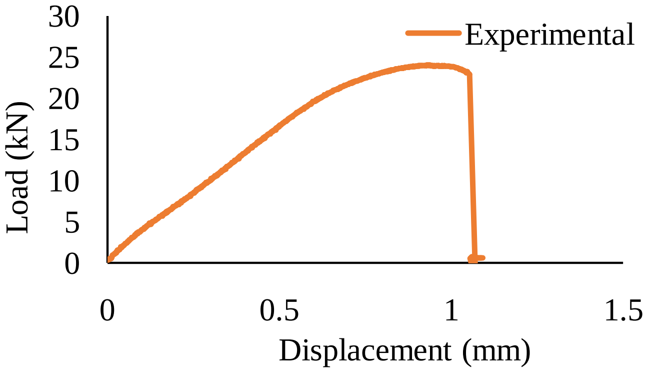

Figure 7.5: Grahical Representation Of Load - Displacement Curve

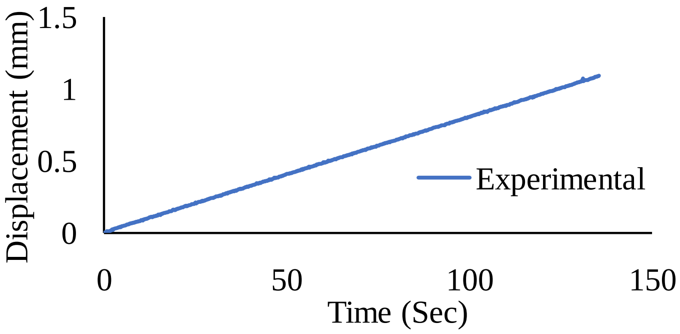

Figure 7.6: Graphical Representation Of Displacement – Time Curve

The load-displacement curve shown in figure 7.5 measures the extrinsic qualities of a specimen. Stiffness, work to failure, ultimate load and displacement are the major parameters.Figure 7.6 illustrates how displacement-time graphs exhibit how a moving object's displacement evolves over time. On a graph of displacement vs. time, an item is said to be stationary if the line is horizontal, On a displacement-time graph, an item is said to be moving if its line slopes upward.

7.2.4 NUMERICAL MODELING OF STEEL PLATES WITH ADHESIVE LOCTITE HY4080 FOR VARIOUS OVERLAP LENGTHS:

Tabel7.4: Maximum Load (kN)

Overlap Length Lo (mm)	Maximum Load Pm (N)	Maximum Load Pm (kN)
30	5970.86	5.97086
50	11880.5	11.8805
70	17751.2	17.7512
90	23728.6	23.7286

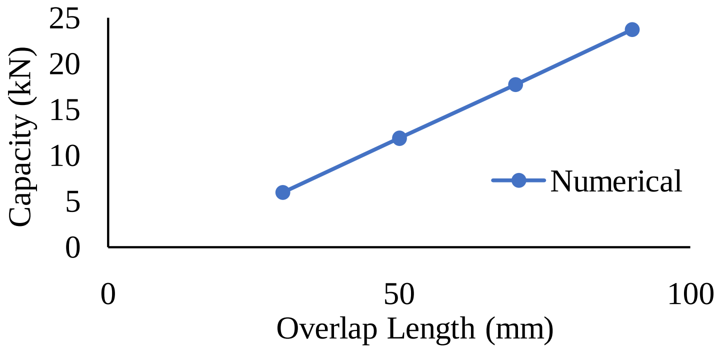

Figure 7.7: An illustration of capacity vs. variety lengths of an overlap for a single lap joint model

The findings of the experiment were compared to numerical data generated by Abaqus® using a cohesive zone modelling module. The joints' strength was anticipated by these studies. The analysis took geometrical non-linearities into consideration. The adhesives received cohesive component treatment, and the adherends were modelled as continuum elasto-plastic bodies for the strength research.The adherends in the models of joints in two dimensions were mostly constructed using quadrilateral plane-strain components.The capacity vs overlap length graph is then shown, and it can be seen in fig. 7.7 that load rises as overlap length increases. This suggests that overlap length is a crucial model parameter and that it is one of the most critical variables affecting joint strength (LO). The programme Abaqus is used for this. As a result, it can be observed that the CZM is a reliable method for determining the strength of bonded joints.

VIII. SUMMARY AND CONCLUSION

In this project numerical modelling of crack growth in composite joints has been attempted. For this purpose, two broad type of methods of modelling are used namely cohesive zone modelling (CZM) and ductile damage modelling (DDM). All the numerical simulations are performed using ABAQUS. The CZM has again been implemented in two ways: through method of interaction & method of implementation of cohesive elements (COH2D4). In order to validate the methodology the capacity of lap joints of various overlap lengths are taken from literature, the same models are numerically simulated and the results are compared in this thesis. This has been demonstrated for two different cases of substrates:

1. Aluminium plates bonded by adhesive.
2. CFRP composite plates bonded by adhesive.

In the second method ductile damage model (DDM), different adherend properties for different overlap lengths and different thickness for one case of overlap length is studied. The DDM generally is more robust and is able to incorporate advanced failure parameters like stress triaxiality, strain rate, failure strains. Though the method can account for different strain rates, in this study effect of strain rate is not considered although it is not a limitation. Also the thickness of adhesive can be modelled in the DDM method. However, major drawback observed in the DDM method is that it cannot account for mixed more fracture. Though the fracture taking place in a lap joint is of mixed mode nature (both mode I and II occur together), the load transfer is predominantly through shear behaviour. Hence, in DDM the strength predicted is not accurate as the CZM, but in reasonable agreement with the experiment and needs further study.Since, the CZM methodology is able to predict more accurately the adhesive connection between composite plates, as well as metallic plates,this has been further used to simulate an inhouse experiment using HY4080 adhesive commercially available in India.

Experiments are conducted using lap joints made of steel plates bonded by adhesive HY4080. The appropriate CZM parameters are identified based on the physics of the problem through trial and error. The shear strength, toughness are estimated based on physics and fine tuned based on the experimental load-deformation curve and the numerical load-deformation curve. The finalized properties of HY4080 adhesive are used in numerical modeling of a single lap joint model to predict capacity for different overlap lengths. In this model it is observed that The load grows as the overlap length does as well.

The following conclusions are drawn from the thesis work:

1. Among other parameters, the interfacial fracture energy has a significant impact on the bond strength (or ultimate load) of such bonded joints.
2. Nonlinear adhesives has lower elastic modulus but a higher deformation capacity with substantially higher interfacial fracture energy than brittle adhesives.
3. Fracture parameters of HY4080 adhesive for modelling through CZM has been identified through inverse analysis, which can be used for several applications of bonded composite joints including in aerospace and construction.
4. The strength obtained for the 40mm width specimen is high enough to cause yielding of steel plates in the experiment. Further strength can be achieved through special surface preparation methods such as etching or grit blasting. This could further increase the use of these adhesive joints.
5. DDM method has the capability to handle adhesives under different rate of loadings or strains. The method also is able to handle ductile adhesives through plastic property definitions. However, the failure criteria does not account for mixed mode fracture. Hence, there needs further study in understanding how mixed mode fracture can be studied using this versatile method.
6. As a result, it can be said that CZM is a reliable method for estimating the strength of bonded joints.The method using the interface interaction is easy to implement. The method using the COH2D4 elements is slightly tedious since it involves more number of elements to model the interface (i.e., the adhesive is modelled as a solid block in-between the plates). However, the effect of thickness can be naturally accounted in this method since the adhesives is modelled with thickness. Both ways are found to accurate.
7. Further the methodology in this thesis is generalised and can be extended for cyclic loading and impact loading as well.

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