CHAPTER 7

Stress Analysis of Adhesively Bonded Cylindrical Joint using FEA

7.1 Modelling the Behaviour of Adhesive Joint

Abaqus offers a library of cohesive elements to model the behaviour of adhesive joints, composite interfaces etc.

The Abaqus cohesive elements library includes

- Elements for 2D analysis
- Elements for 3D analysis
- Elements for axisymmetric analysis

The designation of cohesive element is as shown in fig.(7.1) below.

![Cohesive element designation](image)

Cohesive elements are used to model adhesive between two components, each of which may be deformable or rigid.
The special representation of cohesive element is as shown in fig.(7.2).

Cohesive element with continuum approach assumes that the cohesive zone contains material of finite thickness that can be modelled using the conventional material models. The constitutive response of cohesive element modelled as continuum can be defined in terms of macroscopic material properties such as stiffness and strength using conventional material model.

The cohesive elements can be included in the model by embedding one or more layer of cohesive elements in the mesh of existing model.

The connection at the interface between the cohesive layer and the surrounding bulk material can be defined by sharing nodes or by defining tie constraints.

The tie constraint approach allows to model cohesive layer by using a finer discretization than that of the bulk material which is more desirable in many modelling situations.

If it is required to use finer mesh in cohesive layer then one should construct the cohesive layer as a separate part. Mesh the surrounding bulk material into two regions with the spacing equal to thickness of adhesive layer. Mesh the cohesive layer and tie the cohesive layer to the surrounding bulk material using tie constraints.

The connectivity of a cohesive element is like that of continuum element, but it is useful to think of cohesive element as being composed of two faces (a bottom and a top face) separated by the cohesive zone thickness. The relative motion of top and bottom faces measured along the thickness direction represents opening and closing of the interface. The relative change in the position of top and bottom faces measured in the plane orthogonal to the thickness direction quantifies the transverse shear behaviour of the cohesive element.

To avoid numerical problems, it is recommended that one should model the geometry using values $10^{-4}$ or greater for the thickness.
Often the cohesive elements completely degrade in tension and/or shear as a result of deformation. Subsequently, the components that are initially bonded together by cohesive elements may come in contact with each other. This kind of contact can be handled by the cohesive element itself. By default, cohesive elements retain their resistance to compression even if their resistance to other deformation modes is completely degraded. As a result, the cohesive elements resist interpenetration of the surrounding components even after the cohesive element has completely degraded in tension and/or shear. This approach works best when the top and the bottom faces of the cohesive element do not displace tangentially by a significant amount relative to each other during the deformation i.e. the deformation of the cohesive element should be limited to ‘small sliding’.

It is important to define the orientation of cohesive element correctly, since the behaviour of the element is different in thickness and in-plane direction. By default the top and bottom faces of cohesive elements are as shown in fig.(7.3) for three dimensional cohesive elements.
To compute thickness direction for three dimensional elements, a mid surface is formed by averaging the coordinates of the node pairs forming the bottom and top surfaces of the element. Then normal to mid surface gives the thickness direction and the positive direction is obtained with right hand rule going around the nodes of the element on the bottom or top surface as shown in fig. (7.4).

For adhesive layer with finite thickness it is assumed that the cohesive layer is subjected to only one direct component of strain, which is through thickness strain, and two transverse shear strain components. The other two direct components of the strain and in-plane shear strain are assumed to be zero for the constitutive calculations.

7.2 Finite Element Modelling using ABAQUS

Both the shafts and adhesive layer are modelled with the pre-processor of ABAQUS as shown in figure (7.5(a)). For meshing shafts the element used is C3D8R with global seed size as 1.5 and adhesive layer is meshed using element COH3D8 with global seed size as 1.5. The shafts and adhesive layer are assembled by defining tie constraint as shown in figure (7.5(b)). One end of the assembly is fixed by selecting end face of shaft and boundary condition as ENCASTRE and the torsional moment is applied at the other end. The different cases are analysed by varying the assembly bond length and varying the diameters of shaft 1 and shaft 2 there by varying adhesive thickness.
Fig. 7.5(a) : Modelling of shaft assembly

Fig. 7.5(b) : Meshing of shaft assembly
7.3 Results of Finite Element Analysis

The results of Finite Element Analysis for Case 1: Steel shafts with LOCTITE 620 adhesive having bond clearance 0.2 mm and bond length varied from 10 mm to 35 mm are shown in figure (7.7 (a),(b),(c)). The results of Finite Element Analysis are compared with Experimental values in table (7.1) and graphical comparison is shown in figure (7.8).

7.3.1 Case 1: steel shafts with LOCTITE 620 adhesive with bond clearance constant and bond length varied

Steel_Steel_L10_t0.20

Fig. 7.7 (a): FEA of Steel shafts bonded with Loctite 620 with bond clearance constant, ta=0.2 mm
Fig. 7.7 (b): FEA of Steel shafts bonded with Loctite 620 with bond clearance constant, $ta=0.2$ mm
Table 7.1 : Comparison of Experimental and Finite Element Analysis results of Steel shafts bonded with Loctite 620 with bond clearance constant , ta=0.2 mm
The results of Finite Element Analysis for Case 2: Steel shafts with LOCTITE 620 adhesive having bond length 20 mm and bond clearance varied from 0.11 mm to 0.40 mm are shown in figure (7.9 (a),(b),(c)). The results of Finite Element Analysis are compared with Experimental values in table (7.2) and graphical comparison is shown in figure (7.10).

### 7.3.2 Case 2: Steel shafts with LOCTITE 620 adhesive with bond length constant and bond clearance varied

Fig. 7.9 (a): FEA of Steel shafts bonded with Loctite 620 with bond length constant, L=20 mm
Fig. 7.9(b): FEA of Steel shafts bonded with Loctite 620 with bond length constant, \( L=20 \text{ mm} \)
Steel_Steel_L20_t0.40

Fig. 7.9(c): FEA of Steel shafts bonded with Loctite 620 with bond length constant, L=20 mm

<table>
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<tr>
<th>Sr.No.</th>
<th>Material of Shafts</th>
<th>Adhesive</th>
<th>ta (mm)</th>
<th>L (mm)</th>
<th>FEA T\text{failure} (N.m)</th>
<th>Expt. T\text{failure} (N.m)</th>
<th>% Error</th>
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<td>1</td>
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<td>-14.03</td>
</tr>
</tbody>
</table>

Table 7.2: Comparison of Experimental and Finite Element Analysis results of Steel shafts bonded with Loctite 620 with bond length constant, L=20 mm

Fig. 7.10: Comparison of Failure Torque by Experimental and Finite Element Method for Steel shafts bonded with Loctite 620 with bond length constant, L=20 mm
7.4 Finite Element Analysis Deductions

- There is a reasonable agreement between the predicted failure torque by Finite Element Analysis and the experimental results. (% relative error is less than 17%).
- Experimental values of failure torque obtained are more than Finite Element Analysis values.
- The maximum interface shear stress occurs at the ends of the joint.
- The maximum interface shear stress occurs at the end of stiffer shaft.
- As the bond length increases the maximum stress in adhesive layer decreases and hence the torque transmission capacity increases.
- As the bond clearance increases the maximum stress in adhesive layer decreases and hence the torque transmission capacity increases. After a particular Bond clearance there is no further decrease in stress and hence the torque transmission capacity remains almost same.