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Analysis of Bonded Tubular Single Lap Joints subjected to varying Torsion at constant Pressure

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Abstract

The present research deals with Finite Element Method (FEM) based stress and failure analyses of different types of adhesive bonded tubular joint configurations, viz. Tubular Single Lap Joint (TSLJ) and Tubular Socket Joints (TSJ). The bonded joints have been made with laminated FRP composites and have been subjected to different loading conditions viz. circumferential, axial, and torsion. Suitable APDL codes have been developed using ANSYS 14.0 which is capable of capturing the stresses three dimensionally within the joint region. The developed FE model has been validated with respect to analytical results available in literature and found to be in good agreement. Three-dimensional stresses within the joint and different adherend-adhesive interfaces which in turn play key roles in initiating the failures have been studied in details. Locations prone to adhesion and cohesion failures in the overlap or coupling regions have been identified using Tsai-Wü and Parabolic yield criteria based failure indices. Suitable joint parameters and ply-orientations for the laminated FRP composite joints have been suggested in order to improve the performance and resistance of the bonded tubular structures against failures.

Keywords:

Finite Element Method (FEM)
Tubular Single Lap Joint (TSLJ),
Tubular Socket Joints (TSJ)
FibreReinforced Polymer (FRP)

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Introduction

As alternative to conventional engineering materials, Fiber-reinforced polymer (FRP) composites are becoming increasingly popular in the engineering applications. The unique characteristics of FRP, such as their light weight, their resistance to corrosion, high energy absorption, and the lower cost of transportation, erection and maintenance, are very promising in the application of FRP in various engineering fields. Bonded tubular structures made with FRP composites have been common structures in various fields of engineering. Three

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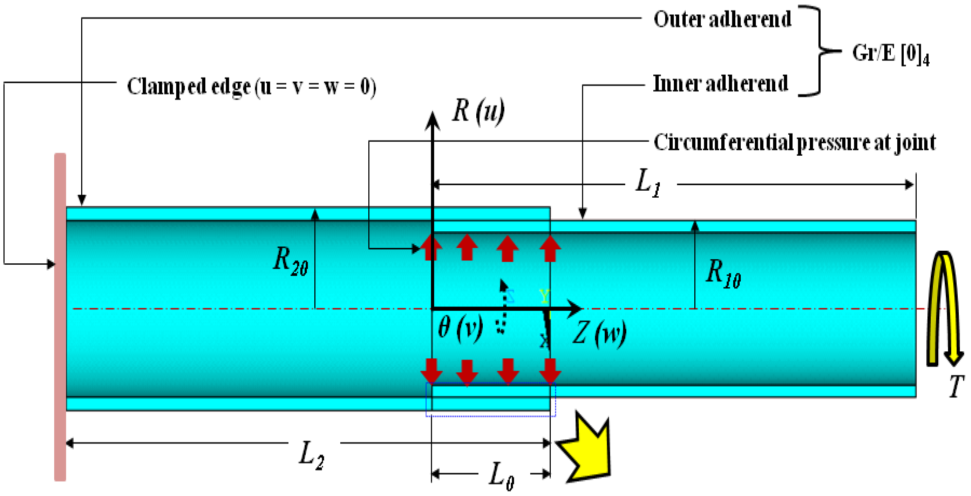
dimensional stress analyses of these structures under internal pressure and torsion have already been discussed in details in chapters 4 and 5. The purpose of the present chapter is to study the combined effect of internal pressure and torsion on stress distributions and failure within the joint region. Special attention has been devoted to study the effect of torque increase at constant pressure on the failure prone regions.



Geometry	Parameter	Magnitude
Adherend lengths	L_1 (Inner adherend) = L_2 (Outer adherend)	102.5mm
Overlap length	L_0	25 mm
Adherend thickness	t_1 (Inner adherend)=t_2 (Outer adherend)	2mm
Adhesive thickness	t_a	0.15 mm
Outer radius of adherends	R_{10} (Inner adherend) R_{20} (Outer adherend)	14.40 mm 16.55 mm

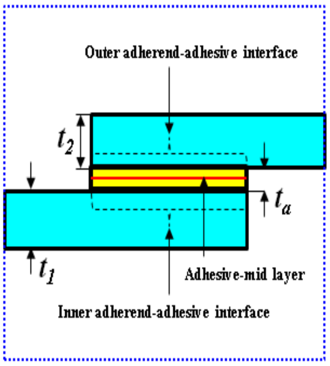


Figure 6.1.Specimen geometry and boundary conditions of the bonded single lap joint along with different interfaces at the joint region.

7.2 Specimen geometry and boundary conditions

Figure 6.1 of the previous chapter shows geometry, configuration, loading and boundary conditions of the bonded TSLJ specimen analyzed in the present study. Two Gr/E $[0]_4$ laminated FRP composite tubes which are similar with respect to length, thickness, and properties have been used as adherends. Here zero degree fiber orientation indicates circumferentially wound fibers. The two tubes have been joined through a thin layer of adhesive (epoxy) as shown in the Figure 6.1. of the previous chapter. The bonded TSLJ have been subjected to an internal pressure of 10 MPa at the inner adherend as well as torsion loading of 100 N-m (direction of the applied torque is CCW as we see from the free end of the bonded TSLJ) at the free end of the bonded TSLJ structure. Torsion loading has been varied as 100 N-m, 110 N-m, 120 N-m, and 130 N-m for a constant internal pressure of 10 MPa in order to study the effect of torsion loading variation on joint strength. The material properties along with strength values for adhesive and adherends have been given in Table 4.1 which have been considered from the work of Das and Pradhan (2010).Three different bondline interfaces have been identified to be the critical regions prone to stress concentration effects in the present analysis: (i) inner adherend-adhesive interface, (ii) adhesive mid-layer, and (iii) outer adherend-adheive interface (Figure 6.1).

7.3 Finite element modelling

The bonded TSLJ has been modelled using the FE codes of ANSYS 14.0. The FE mesh of the bonded TSLJ specimen has been shown in Figure 4.2. The modelling and simulation techniques have already been explained in previous chapters (chapter 3 and 4)

7.4 Results and discussion

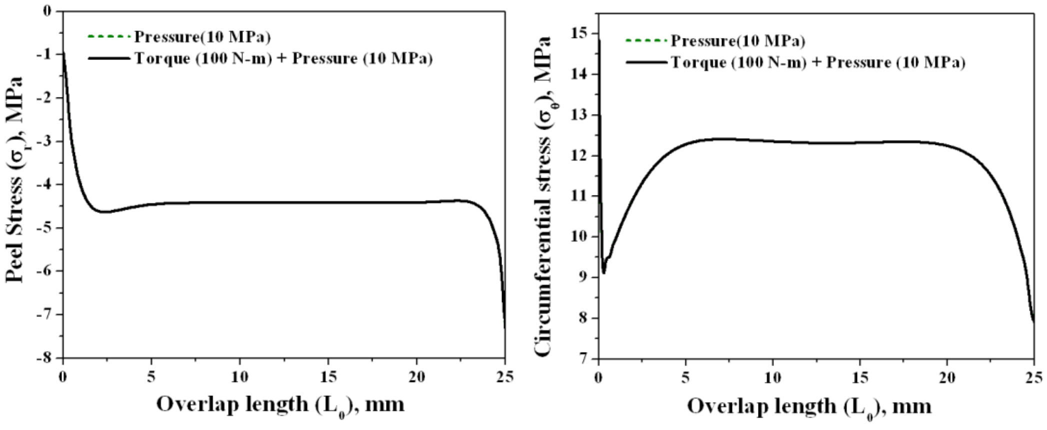
Three dimensional stress distributions within the joint region of the bonded TSLJ have been studied in details for pure internal pressure loading and pure torsional loadings in chapters 4 and 5, respectively. In the present chapter effect of torsion loading on the stress distributions within the joint region is intended to be studied when the bonded TSLJ is already under the application of an internal pressure loading at the inner adherend. Effect of torsion loading (100 N-m) on stress distributions and failure indices at different bondline interfaces of the bonded TSLJ subjected to internal pressure loading of 10 MPa has been studied in the first phase of the analysis. Thereafter, the torsion loading has been increased as: 100N-m, 110N-m, 120 N-m, and 130 N-m for a constant internal pressure of 10 MPa and effects have been studied corresponding to the critical bondline interface.

7.4.1 Effect of Torque in presence of Internal Pressure on stresses in joint

7.4.1.1 Inner adherend-adhesive interface

It has already been observed in chapter 4 (Figure 4.3) that under influence of internal pressure, four stress components (σ_r, σ_θ, σ_z, and τ_{rz}) at the inner adherend-adhesive interface are of considerable magnitude. Whereas, the rest shear stress components ($\tau_{r\theta}$, $\tau_{\theta z}$) are of negligible magnitudes. However, for a pure torsional loading, an exactly opposite scenario has been observed. In this case, the negligible stress components in case of pure pressure loading ($\tau_{r\theta}$, $\tau_{\theta z}$) becomes the most prominent stress components (Figure 5.2 (d), (e)).

(a)(b)



(c) **(d)**

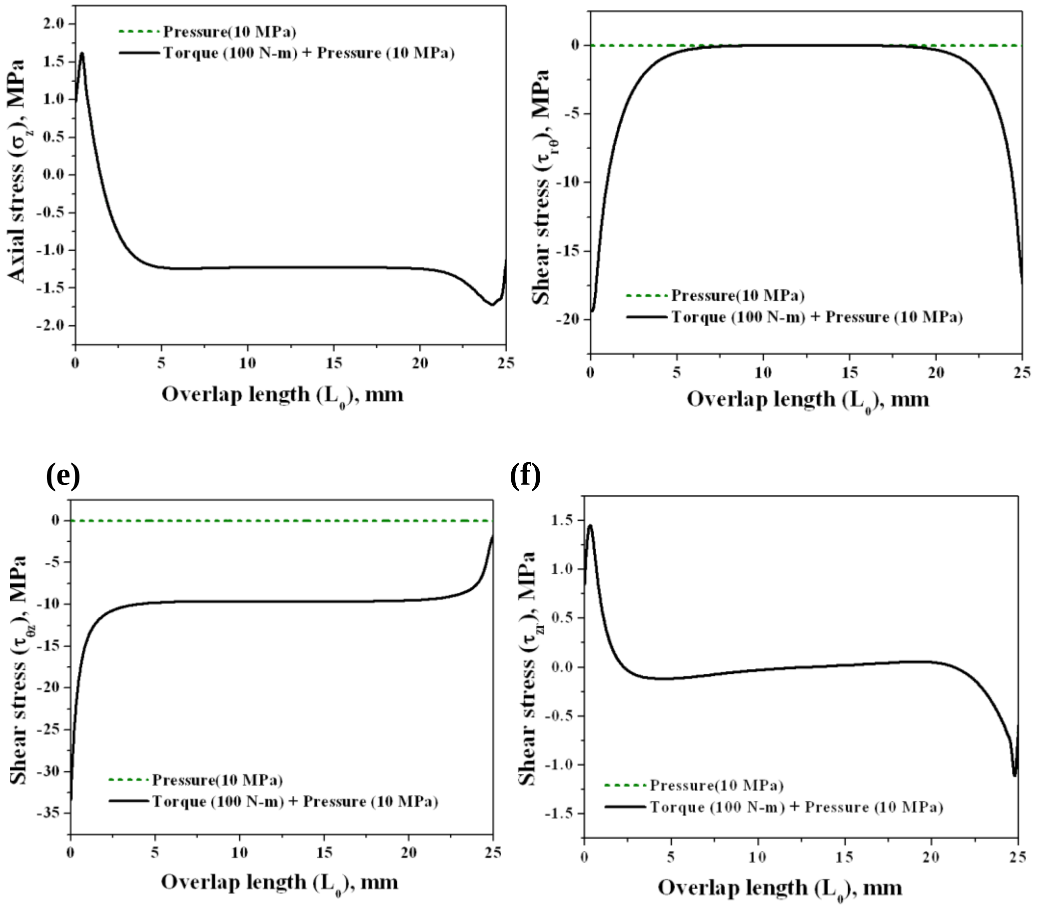


Figure.7.1. Effect of introduction of torsion loading in presence of internal pressure on stress distributions at the inner adherend-adhesive interface.

Whereas, the most prominent stress components for pure pressure loading (σ_r, σ_θ, σ_z, and τ_{rz}) are of negligible magnitudes as already explained in chapter 5 through Fugures 5.2 (a), (b), (c), and (f). The present case is just a superposition of these two cases.

The stress distributions also seem to be following a superposition trend as seen from the below figures. Introduction of torsional loading in the joint region enhances the magnitude of shear stresses ($\tau_{r\theta}$) and ($\tau_{\theta z}$) within the inner adherend-adhesive interface of the bonded TSLJ (Figure 7.1 (d) and (e)). It could be clearly observed that the profile of these stresses ($\tau_{r\theta}$ and $\tau_{\theta z}$) matches exactly with the corresponding stress profiles for pure pressure loading case (Figure 5.2 (d) and (e)). This confirms that the stress distributions follow the superposition principle. Similarly the normal stress profiles (σ_r, σ_θ, and σ_z) and one shear stress profile (τ_{rz}) have been observed to be unaffected due to introduction of torsional loading in presence of the internal pressure. The stress profiles again match exactly with the profiles corresponding to pure internal pressure loading case (Figure 4.3 (a), (b), (c) and (f)) confirming the superposition principle again.

7.4.1.2Adhesive mid-layer

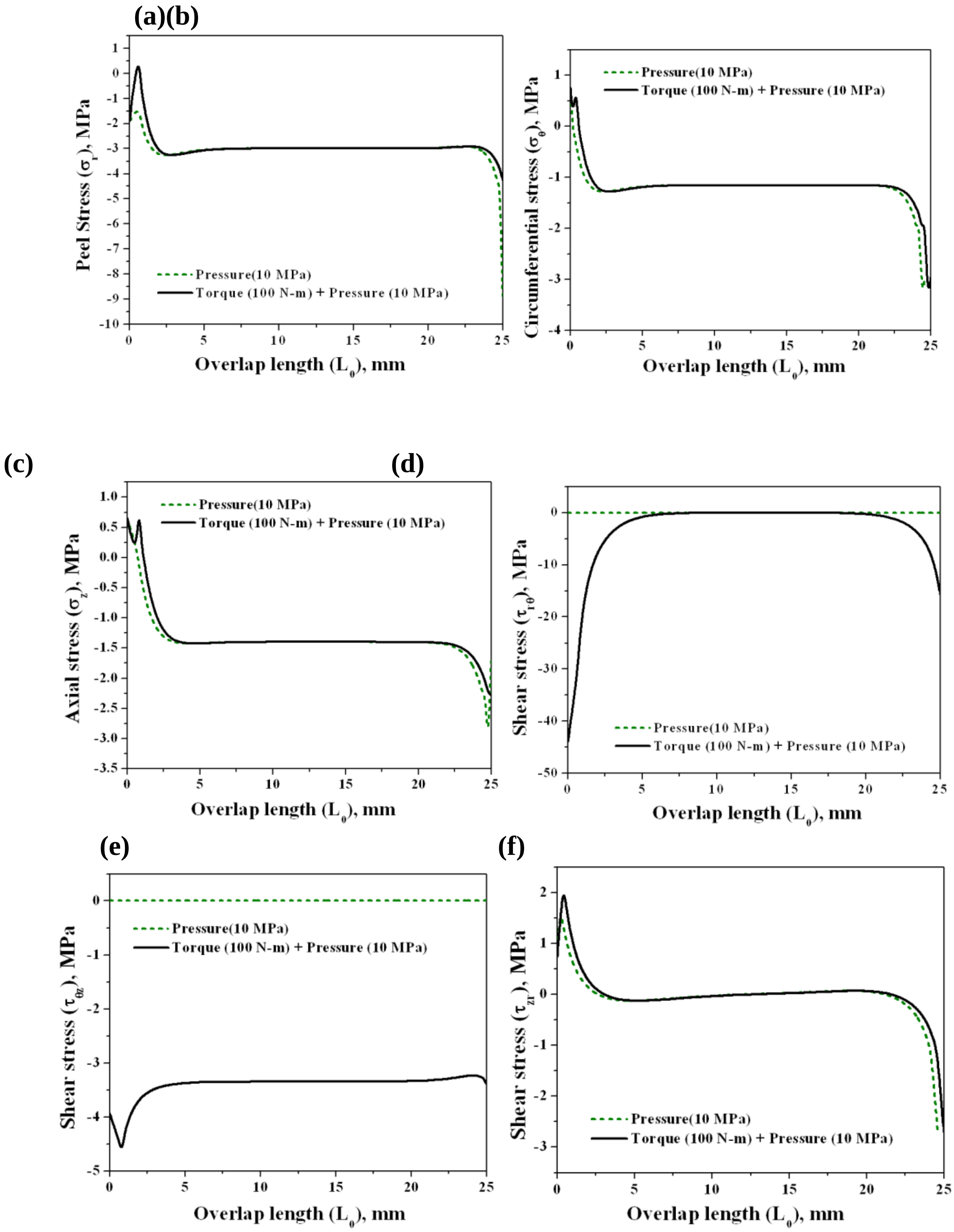


Figure.7.2. Effect of introduction of torsion loading in presence of internal pressure on stress distributions at the adhesive mid-layer.

Introduction of torsional loading of 100 N-m in the joint region enhances the magnitude of shear stresses ($\tau_{r\theta}$ and $\tau_{\theta z}$) within the adhesive mid-layer of the bonded TSLJ (Figure 7.2 (d) and (e)). It could be clearly observed that the profile of these stresses ($\tau_{r\theta}$ and $\tau_{\theta z}$) matches exactly with the corresponding stress profiles for pure torsion loading case (Figure 5.3 (d) and (e)). This confirms that the stress distributions follow the superposition principle. However, the normal stress profiles (σ_r, σ_θ, and σ_z) and one shear stress (τ_{rz}) have been observed to be slightly affected due to introduction of torsional loading in presence of the internal pressure loading confirming slight deviation from the superposition principle.

7.4.1.3 Outer adherend-adhesive interface

When a torsion loading of 100 N-m has been introduced in the joint region in presence of internal pressure loading acting at inner adherend of the bonded TSLJ, it enhances the magnitude of shear stresses ($\tau_{r\theta}$ and $\tau_{\theta z}$) within the outer adherend-adhesive interface (Figure 7.3 (d) and (e)). It could be clearly observed that the profile of these stresses ($\tau_{r\theta}$ and $\tau_{\theta z}$) matches exactly with the corresponding stress profiles for pure torsion loading case (Figure 5.4 (d), and (e)). This confirms that the stress distributions follow the superposition principle. Similarly the normal stress profiles (σ_r, σ_θ, and σ_z) and shear stress (τ_{rz}) have been observed to be unaffected due to introduction of torsion loading in presence of the internal pressure loading.

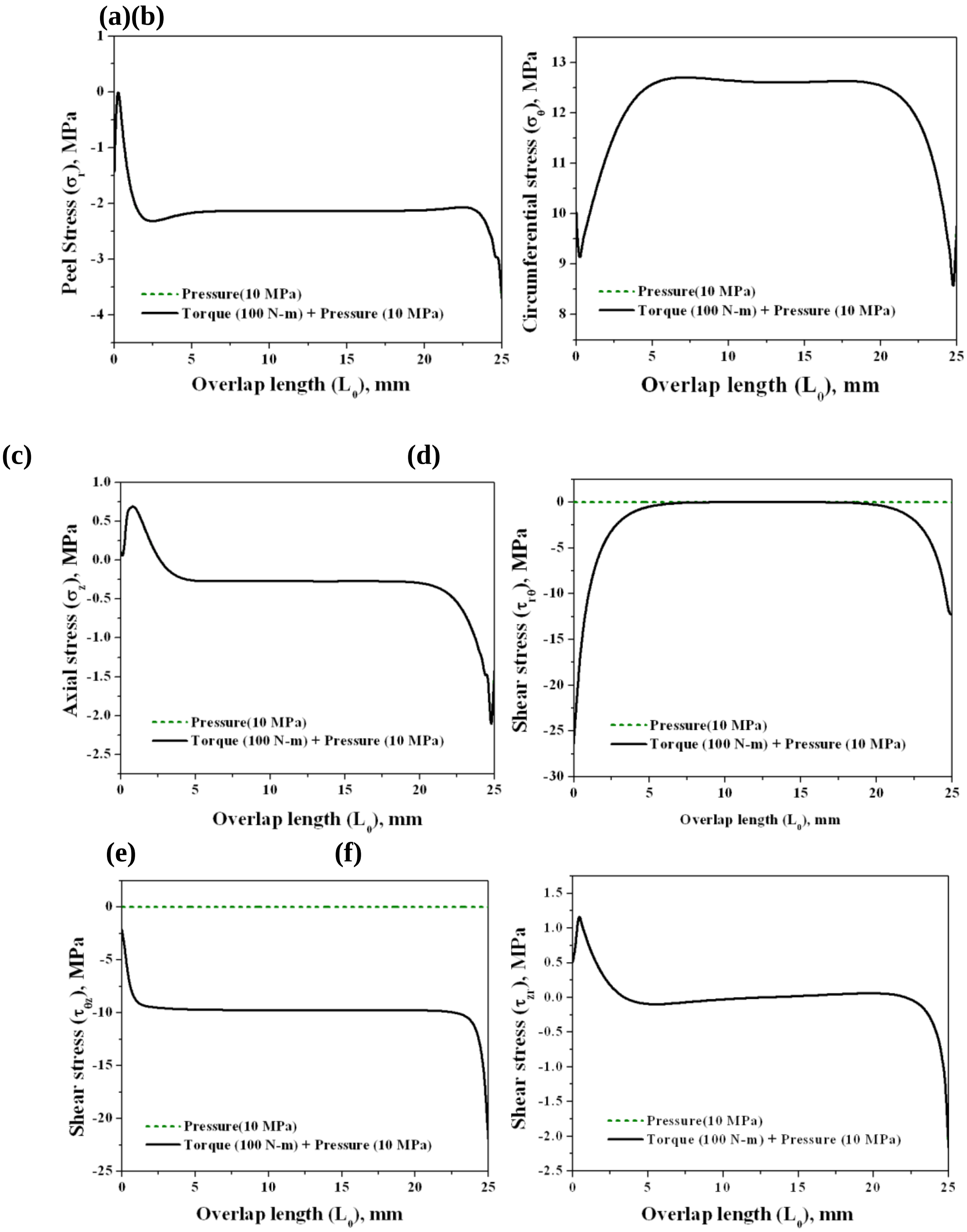


Figure.7.3. Effect of introduction of torsion loading in presence of internal pressure on stress distributions at the outer adherend-adhesive interface.

The stress profiles again match exactly with the profiles corresponding to pure internal pressure loading case (Figure 4.5 (a), (b), (c) and (f)) confirming the superposition principle.

7.4.2 Effect of torsional loading in presence of internal pressure on failure within joint

The failure index profiles for all the bondline interfaces shown in Figure 7.4 (a), (b), and (c) are completely varying as compared to the failure index profiles corresponding to pure internal pressure as shown in chapter 4 (Figure 4.7). This indicates that introduction of torsion loading along with the internal pressure loading is very much affecting the failure index profiles for the different bondline interfaces. It is important to note here that when the bonded TSLJ is subjected to a combination of torsional and pressure loading, effect of torsional loading is predominantly observed on the failure effects within the joint region. Although the internal pressure loading has been observed to be affecting major stress components within the joint region, still it is unable to have a prominent effect as far as failure within the joint region is concerned.

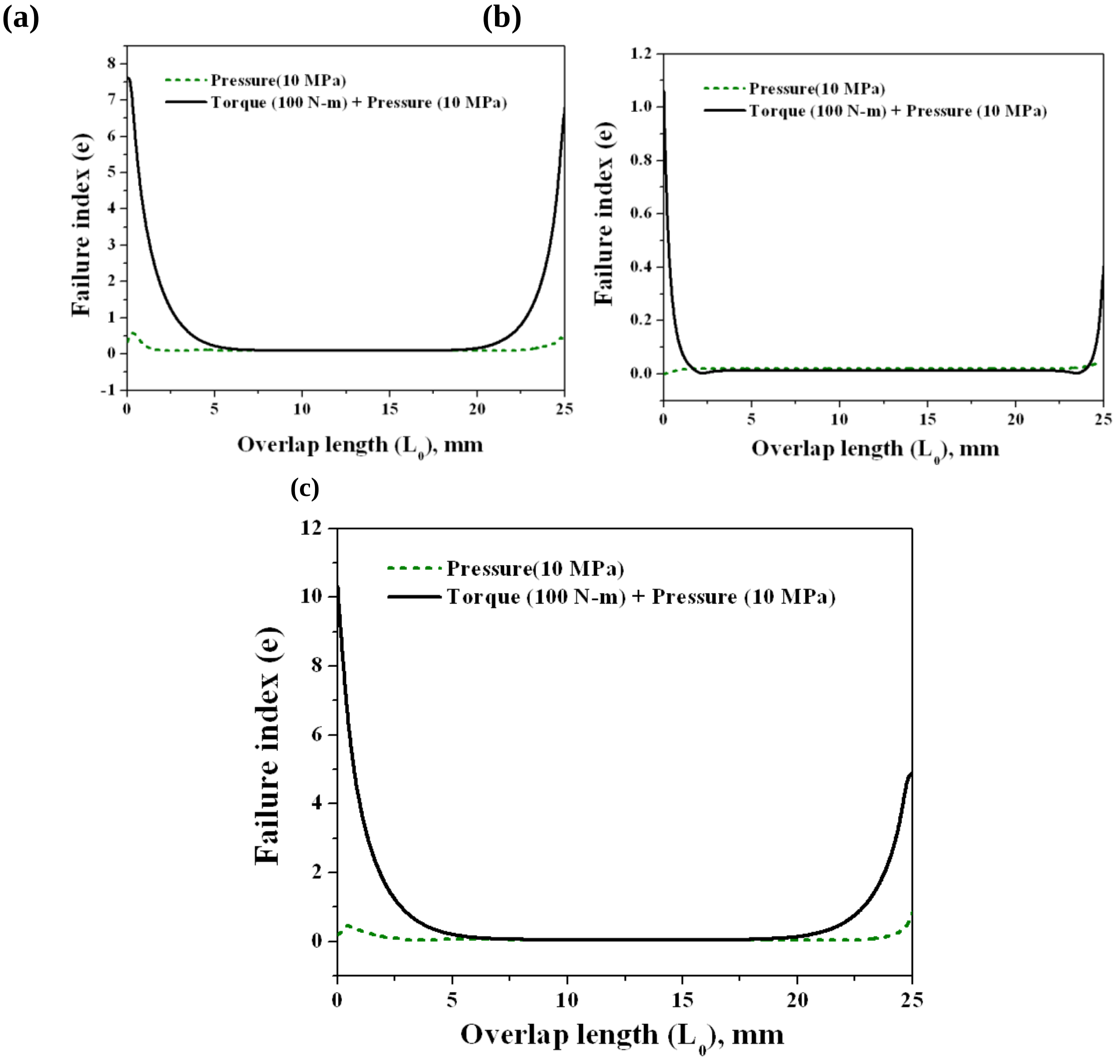


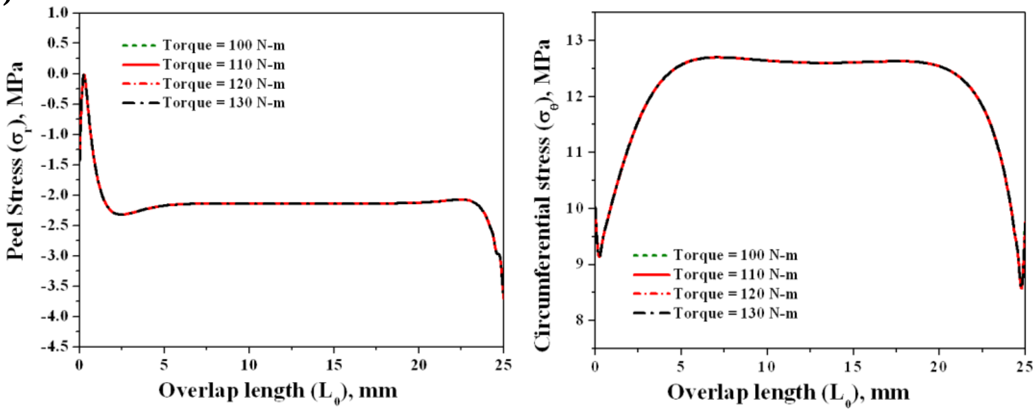
Figure.7.4. Effect of introduction of torsional loading in presence of internal pressure on failure indices at different bondline interfaces: (a) inner adherend-adhesive interface, (b) adhesive mid-layer, and (c) outer adherend-adhesive interface.

This has been clearly observed in Figure 6.5 of chapter 6, where it can be clearly observed that the failure index profiles at all the bondline interfaces match exactly with the failure index profiles for a pure torsional loading case. This indicates that application of pressure with respect to torsional loading does not affect the magnitude of failure indices within the joint region. However, The Failure index profiles at different bondline interfaces of the TSLJ subjected to pressure and torsion (Figure 7.4) reveal that introduction of torsion with respect to pressure is tremendously affecting the magnitude of failure indices. The outer adherend-adhesive interface which has been identified as the critical bondline interface for both pure pressure and pure torsional loading has also been observed to be the layer with maximum failure indices for the case of combined pressure and torsional loading. However, the failure prone region is towards the clamped edge of the bonded TSLJ under combined pressure and torsional loading which again confirms the predominance of the torsional loading.

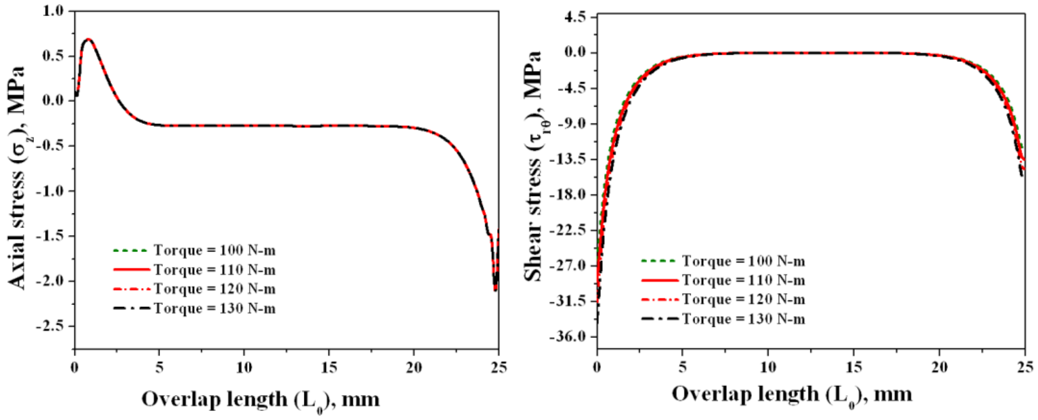
7.4.3 Effect of torque variation in presence of internal pressure on stresses in the critical bondline interface

As the torque has been varied from 100 N-m to 130 N-m in presence of a constant pressure of 10 MPa, it can be observed that only the shear stress ($\tau_{\theta z}$) component have been increasing prominently. The radial-circumferential shear stress component ($\tau_{r\theta}$) has been observed to have mild variations with respect to the torque change.

(a)(b)



(c) (d)



(e) **(f)**

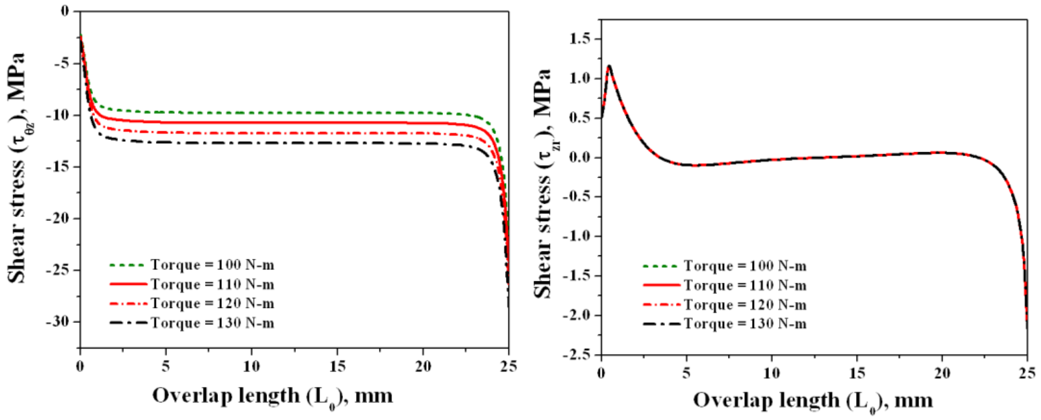


Figure.7.5. Effect of increase in torsional loading in presence of internal pressure on stress distributions within the outer adherend-adhesive interface.

However the remaining shear stress components, τ_{rz}) as well as normal stress component (σ_r, σ_θ, σ_z,) has remained unchanged due to the torque variation (Figure 7.5).

7.4.4 Effect of torque variation in presence of pressure on failure at the critical bondline interface

Although variation of torsion loading at constant pressure has not induce much more impact on the stress distribution at the outer adherend-adhesive interface (Figure 7.5), but it has got a bit effect on the failure index values as shown in Figure (7.6.) So increase in torque has got a little effect on the failure at the critical bondline interface (outer adherend-adhesive interface).

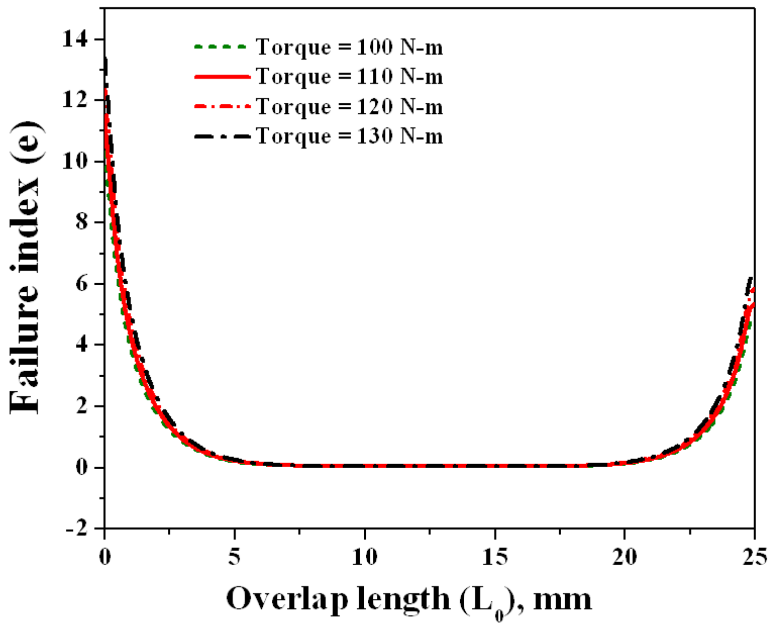


Figure. 7.6 Effect of increase in torque in presence of internal pressure on failure within the outer adherend-adhesive interface.

7.5 Summary and conclusions

Laminated FRP composite made bonded TSLJ subjected to a constant pressure (10 MPa) and varying torsional loading (100 N-m to 130 N-m) has been analyzed through finite element method. The FE codes have been developed through ANSYS APDL in a high speed IBM platform. Stress and failure effects within the joint region have been studied carefully in presence and absence of internal pressure (along with torsional loading). The salient conclusions have been enlisted below.

- Two stress ($\tau_{r\theta}$ and $\tau_{\theta z}$) components within all the bondline interfaces have been enhanced considerably (maintain the same magnitude as in the case of pure torsional loading) due to introduction of torsional loading along with a constant internal pressure.
- However, the remaining stress components (σ_r, σ_θ, σ_z, τ_{rz}) remain unaltered (maintain the same magnitude as in the case of pure pressure loading) due to introduction of torsional loading along with a constant internal pressure.
- Introduction of torsional loading along with the pure internal pressure loading is tremendously affecting the failure index profiles at different bondline interfaces of the TSLJ.
- As the torque has been varied, only two stress components ($\tau_{r\theta}$ and $\tau_{\theta z}$) within the joint have been increasing. However, the remaining normal as well as shear stress components (σ_r, σ_θ, σ_z, τ_{rz},) have remained unchanged.
- Increase in torque in presence of constant pressure has got a considerable effect on enhancing the failure indices at the critical bondline interface (outer adherend-adhesive interface).

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