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A Study on Bond Strenth Between Steel Fibre Reinforced Concrete And Ultra-High Performance Concrete As An Overlay Repair Material

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Abstract
Ultra-High Performance Concrete (UHPC) is used as a material for upgrading reinforced concrete elements due to its improved mechanical and material properties. Numerous experimental studies on the endurance and structural behaviour of retrofitting concrete structures have showed an improvement for quantitatively computing the strength of the composite elements, however, conservative and sometimes erroneous bond strength estimates are used. Furthermore, many roughening methods have been employed to strengthen the bond mechanism; however, no numerical simulation for the force transfer mechanism between the concrete substrate and UHPC as a repair material is less. This paper aims to develop a finite element based model to investigate the bond strength between fiber reinforced concrete (FRC) and Ultra-high performance concrete when used as an overlay repair material under two different conditions under rough and smooth surface conditions. The numerical results shows that rough surface connection is more suitable than smooth surface connection for UHPFRC when bonded together.
Keywords: UHPFRC; interface; bond strength; ANSYS

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I. INTRODUCTION

One of the most critical difficulties in civil engineering applications is the maintenance, rehabilitation, and upgrade of structural components. Furthermore, according to the new design regulations, a substantial number of structures built in the past utilizing previous design codes in various regions of the world are structurally unsafe. Because replacing such weak components of structures costs a lot of money and time, strengthening has become a viable option for increasing load carrying capacity and extending service lives.

The use of ultra-high performance concrete (UHPC) in a variety of applications such as bridge construction, repair and rehabilitation, overlays, building, petroleum industry,hydraulic structures, and architectural components, etc. UHPC is based on three concrete technologies: self-compacting concrete (SCC), high-performance concrete (HPC), and fibre reinforced concrete (FRC) with compressive strengths greater than 126 MPa and post-cracking tensile strengths greater than 5 MPa. UHPC is a mixture of portland cement, sand, quartz powder, silica fume, superplasticizer, water, and steel fibres.

Many researchers have concentrated on employing UHPFRC in constructions dominated by flexure, shear, and torsion due to its excellent fibre bridging capacities at cracked surfaces, resulting in a unique strain-hardening (or deflection-hardening) response with many micro-cracks. Furthermore, due of its increased strength and energy absorption capacity, UHPFRC, along with strain-hardening cementitious composites incorporating polymeric fibres, has been identified as one of the promising materials for impact- and blast-resistant constructions. These qualities can help overcome plain concrete's brittle failure due to its low energy absorption capability for impacts and blasts.

UHPC's remarkable properties make it a viable solution for repairing and retrofitting damaged structural elements, linking precast elements, or as a bridge deck overlay . Although many researchers have used bi-surface, slant shear, push off, and pull-off tests to examine the bond strength between normal concrete and UHPC, there is a knowledge gap linked to numerical modelling of the interfacial bond strength for repair design and evaluation between FRC and UHPC. This work proposes a realistic approach to evaluating the interfacial bond strength between UHPC and FRC using ANSYS finite element (FE) software.

1.1 Literature review

According to the literatures, UHPFRC is a breakthrough in concrete technology, with significantly improved strength, workability, and durability as compared to traditional concrete manufacturing methods. The gains were made possible by reducing the amount of water and aggregates used in particular amounts and sizes, as well as the usage of high-quality silica fume and steel fibres. The amount and sizes of binding differ between UHPFRC and standard concrete .Fibers and a large amount of super plasticizer are examples of such materials. The finer the aggregate grain size, the better. The material arrangement of UHPFRC. Therefore it is significantly denser than that of traditional techniques. The use of a large volume of super plasticizer replaces the use of less water during the procedure improves its workability.

In general, the characteristics generated by UHPFRC show an improvement in permeability quality, heat resistance, as well as impact resistance. The inclusion of fibres, on the other hand, greatly boosts the tensile strength. The compressive strength of UHPFRC, on the other hand, is higher than that of regular concretes, despite the fact that it is not used as the primary criterion for establishing UHPFRC quality. The other tensile and flexure strengths, on the other hand, become very relevant indicators. Based on the findings of quick chloride permeability tests and electron microscope image characterizations, the UHPFRC can also bond successfully, making it a viable alternative material for concrete structural improvements. The UHPFRC has great workability, making it an easy-to-repair material that can be used in field work as a replacement material.

1.2 Applications of UHPFRC:

- Bridges
- Repairs and rehabilitation of concrete structures
- Beam or slab structures using precast or jacket layer methods
- Overlays
- Buildings
- Petroleum industries
- Hydraulic structures
- Architectural components

1.3 Finite element modeling and analysis:

In this paper,a cubical specimen of 150 mm X 150 mm is used to do the analysis. The Fiber reinforced concrete occupies two-third of the volume of the cube and UHPC occupies the other third.

Table 1: Material properties of UHPC

Density	2.3e – 06 kg/mm^3
Young's modulus	52081 MPa
Poisson's ratio	0.2
Bulk modulus	28934 MPa
Shear modulus	21700 MPa
Isotropic secant coefficient of thermal expansion	1.4e – 05 1/^{o} C

Table 2: Material properties of FRC

Density	2.3e – 06 Kg/mm^3
Young's modulus	33042 MPa
Poisson's ratio	0.18
Bulk modulus	17209
Shear modulus	14001
Isotropic secant coefficient of thermal expansion	1.42 – 05 1/^{o} C
Compressive ultimate strength	43.33 MPa
Compressive yield strength	0 MPa
Tensile ultimate strength	5 MPa
Tensile yield strength	0 MPa

1.3.1 UHPFRC Cube with smooth surface condition:

1.3.1.1 Dimensions of sections of UHPC + FRC cube for analysis:

- MATERIAL No. 1 : FRC – M45
- DIMENSIONS – 150 X 100 mm
- MATERIAL No. 1 : UHPC – M130
- DIMENSIONS – 150 X 50 mm

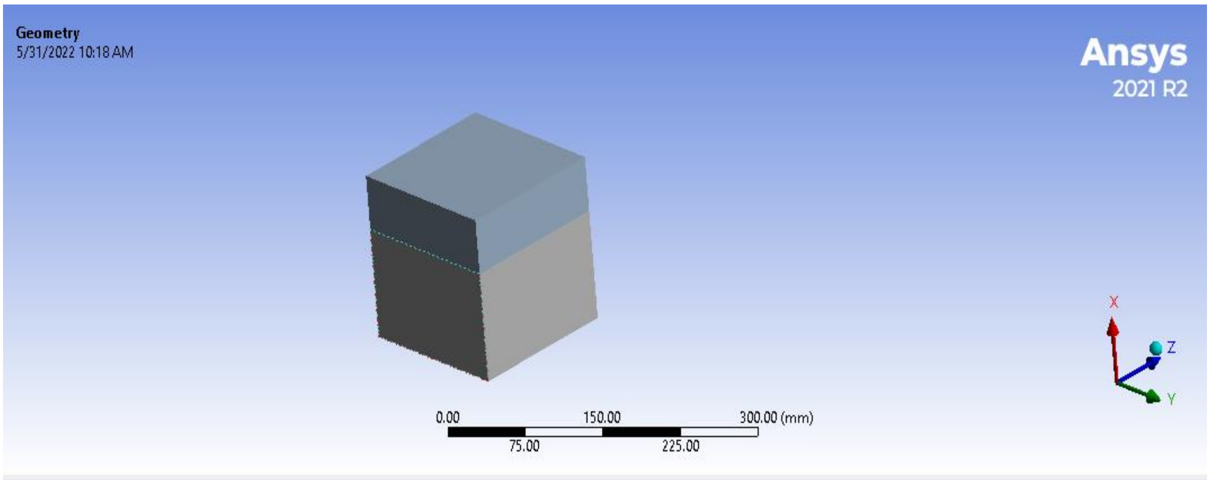

Figure 1: Geometry

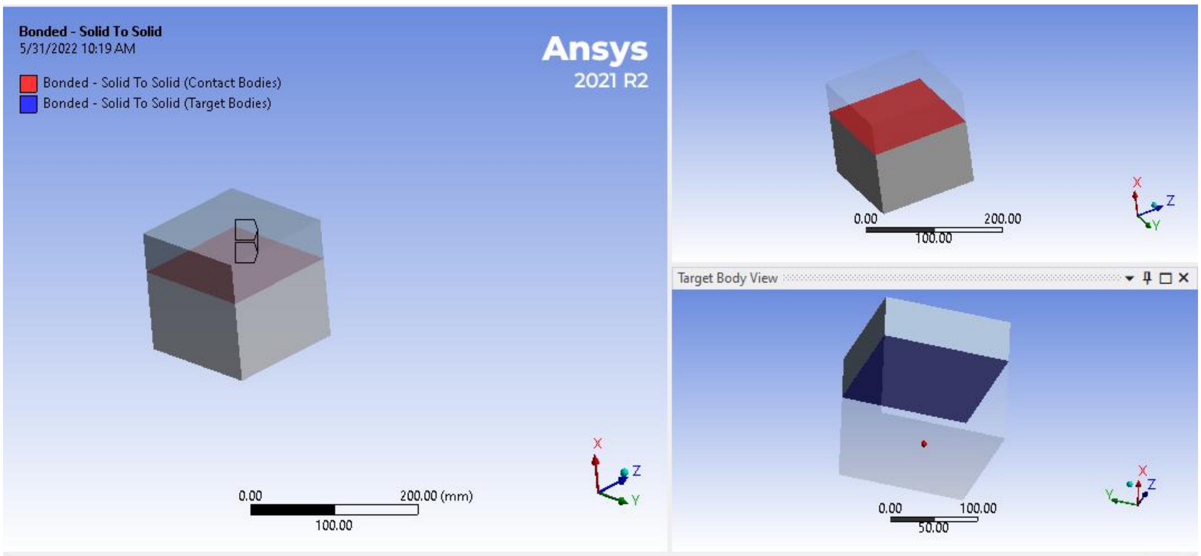

Figure 2: Model showing interfacial bond between FRC and UHPC with smooth surface conditions

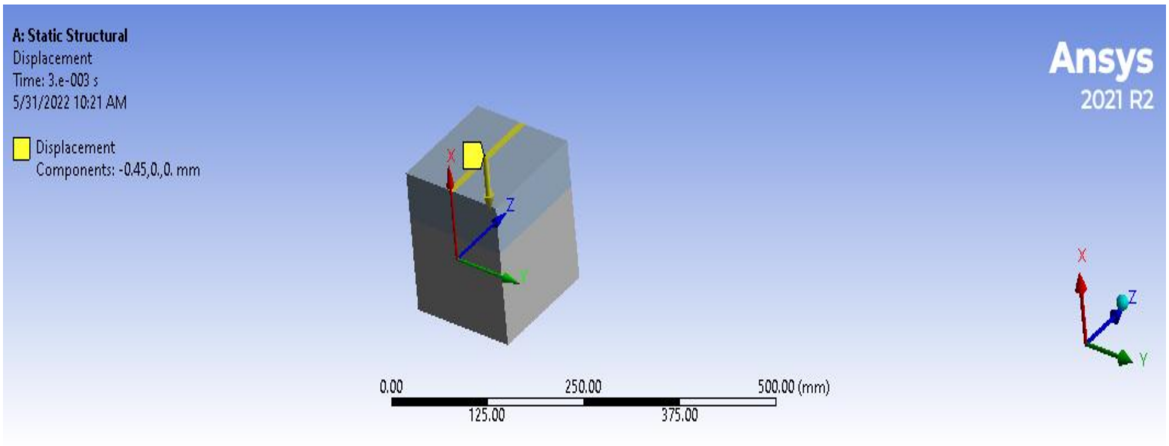

Figure 3: Model showing displacement loading protocol

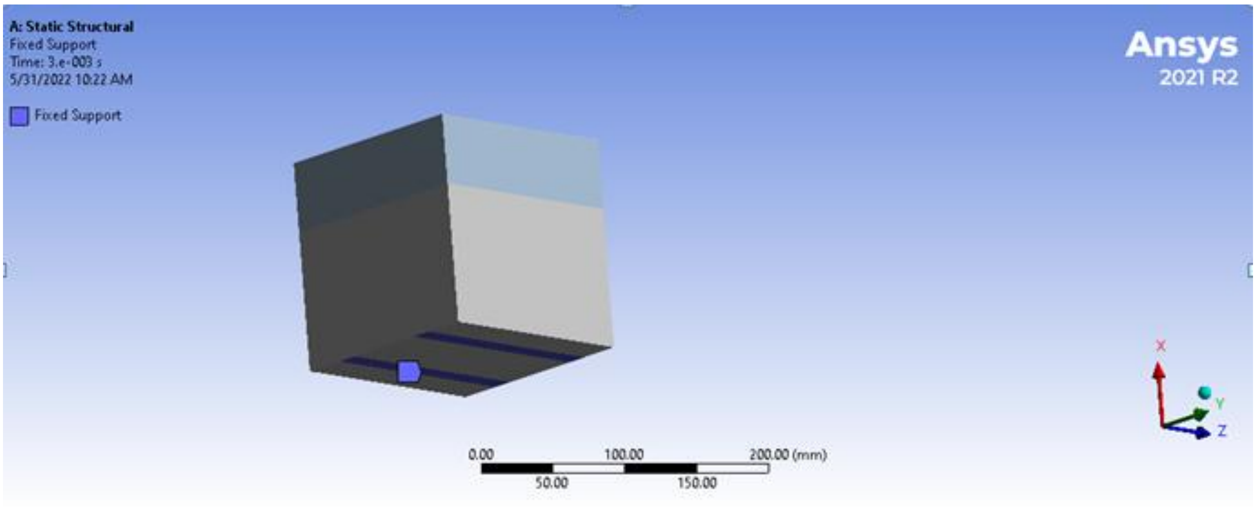

Figure 4: Model showing support conditions

1.3.1.2 Results and discussion:

The results obtained are as follows: (Smooth surface condition)

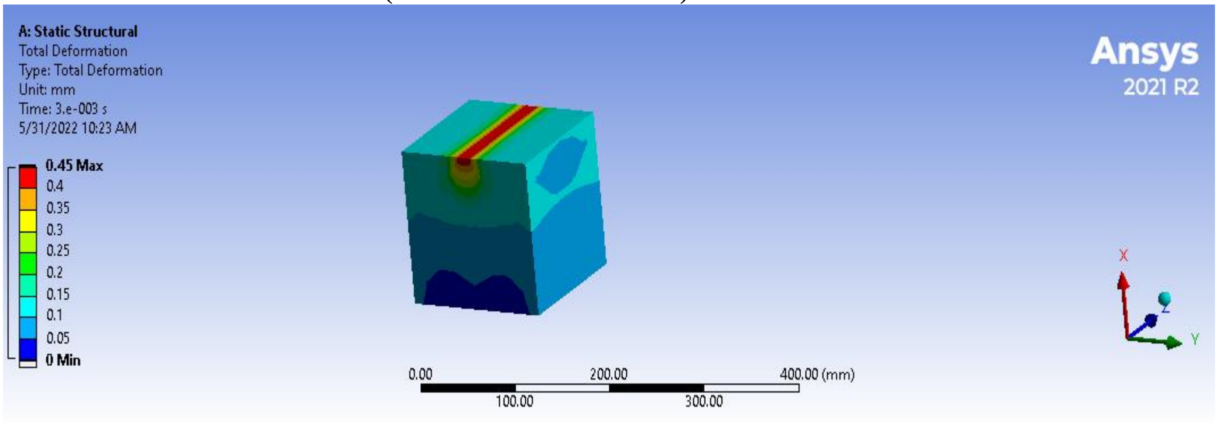

Figure 5: Total deformation pattern

From the figure obtained, maximum deformation occurred at the centre region where the load is applied and its values decrease towards the end. Linear distribution from the load applied position to support condition. It is neutralized, goes down and the load gets discharged. **(Maximum Value: 0.45 mm)**

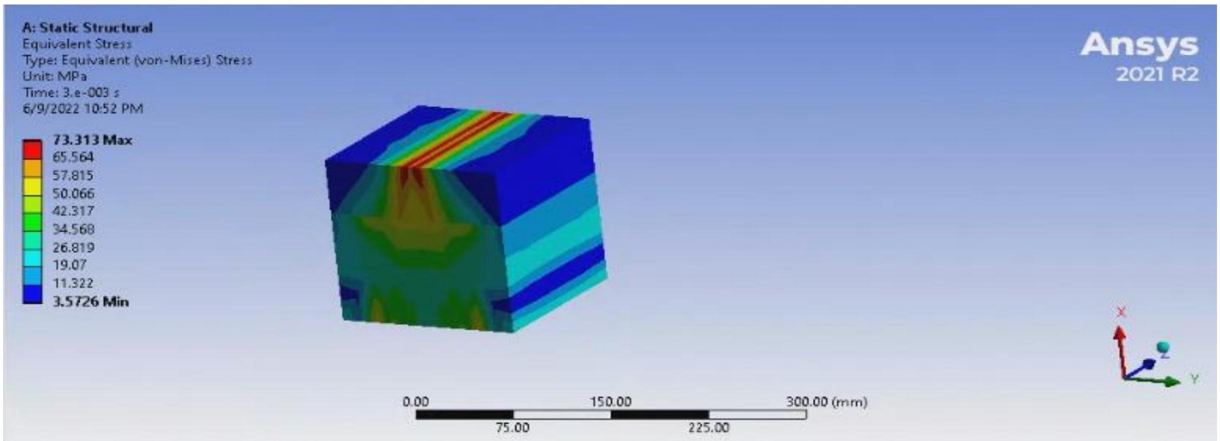

Figure 6: Stress variation

Equivalent (von misces) stress obtained after running the analysis. The stress in figure shows that stress values are more on the upper surface (UHPC region) and it is decreased as it moves down. **(Maximum value: 73.313 MPa)**

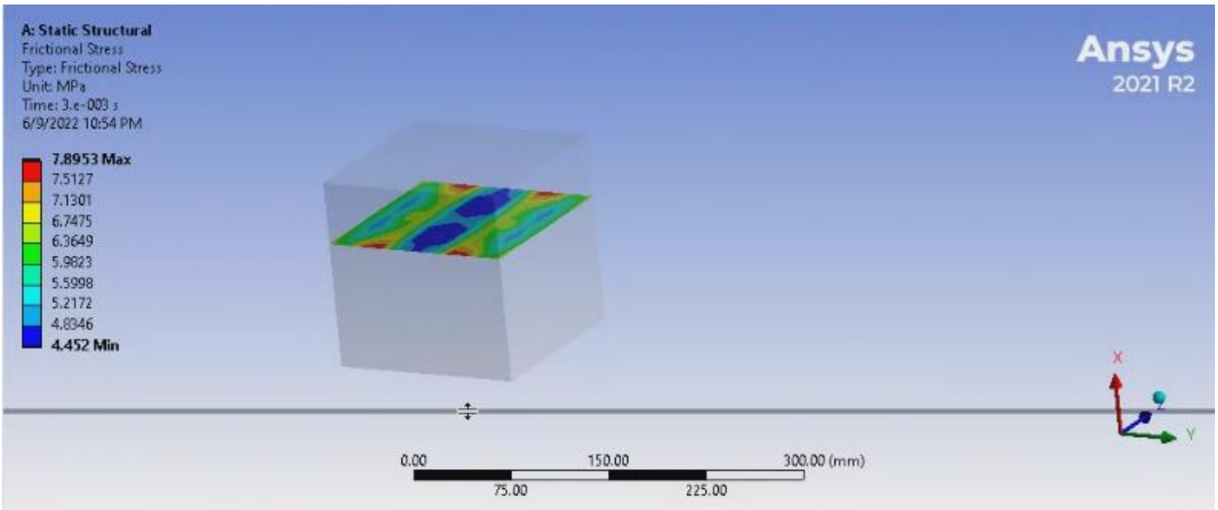

Figure 7: Frictional stress

In this figure, it is seen that load applied on the centre but it holds the maximum stress of 7.8953 MPa on either sides where the red color is obtained at the interfacial layer of UHPFRC. That means the stress value is slowly decreased when it comes to center region of the interfacial layer that is where the blue color is shown. **(Maximum value: 7.8953 MPa)**

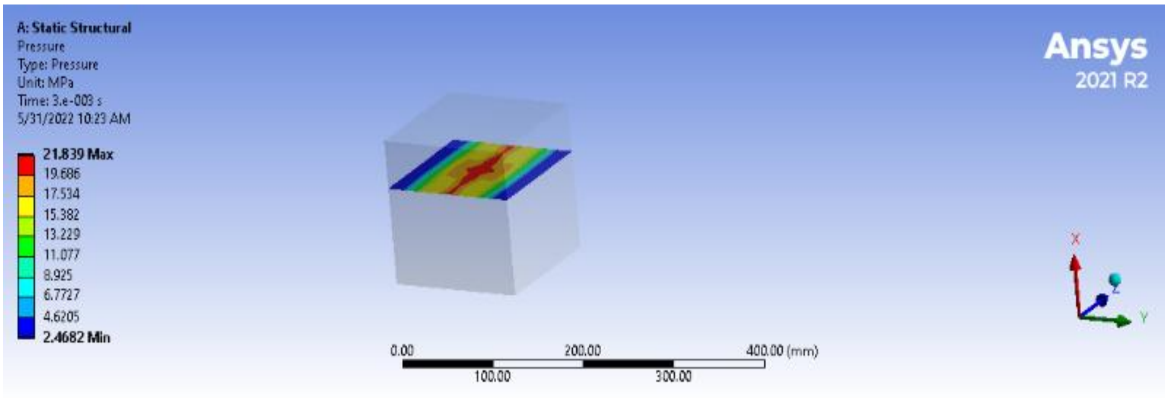

Figure 8: Pressure variation

Pressure is the resistive capacity of applied load. In this figure, the color changes from red to blue in +y direction to –y direction. i.e., pressure variation is maximum at the centre and gets slowly decreased when it moves to either sides of interfacial layer. **(Maximum value: 21.839 MPa)**

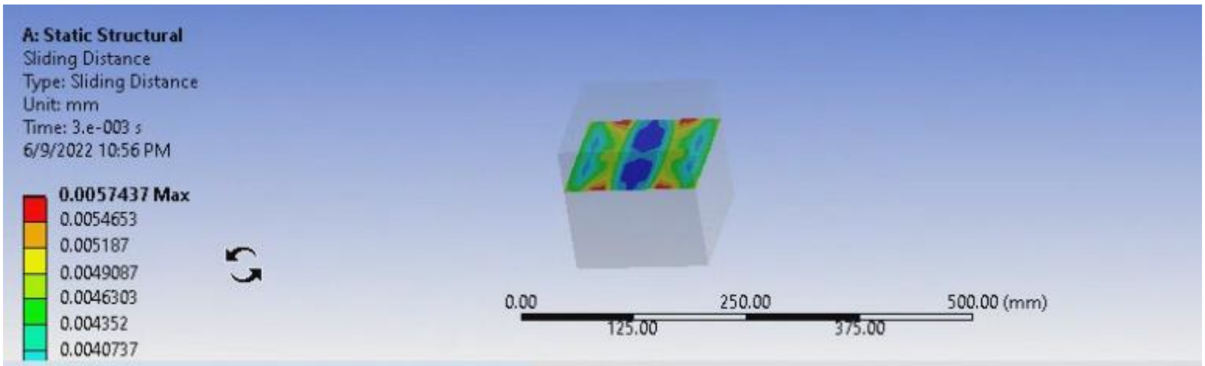

Figure 9: Sliding distance

The sliding distance is the slip of the contact elements as they are being debonde /separated from each other. In this figure, maximum value changes to minimum in horizontal direction. **(Maximum value: 0.0057437 mm)**

Table 3: Displacement V/s Force values on UHPFRC

DISPLACEMENT	FORCE
$-1e^{-002}$	48685
$-2e^{-002}$	86929
$-3.5e^{-002}$	$1.4072e^{005}$
$-5e^{-002}$	$1.8642e^{005}$
$-6e^{-002}$	$1.9836e^{005}$
$-7e^{-002}$	$2.0994e^{005}$
$-8.5e^{-002}$	$2.2657e^{005}$
-0.1	$2.4262e^{005}$
-0.11	$2.5304e^{005}$
-0.12	$2.633e^{005}$
-0.135	$2.7845e^{005}$
-0.15	$2.9326e^{005}$
-0.16	$3.0304e^{005}$
-0.17	$3.1277e^{005}$
-0.185	$3.2725e^{005}$

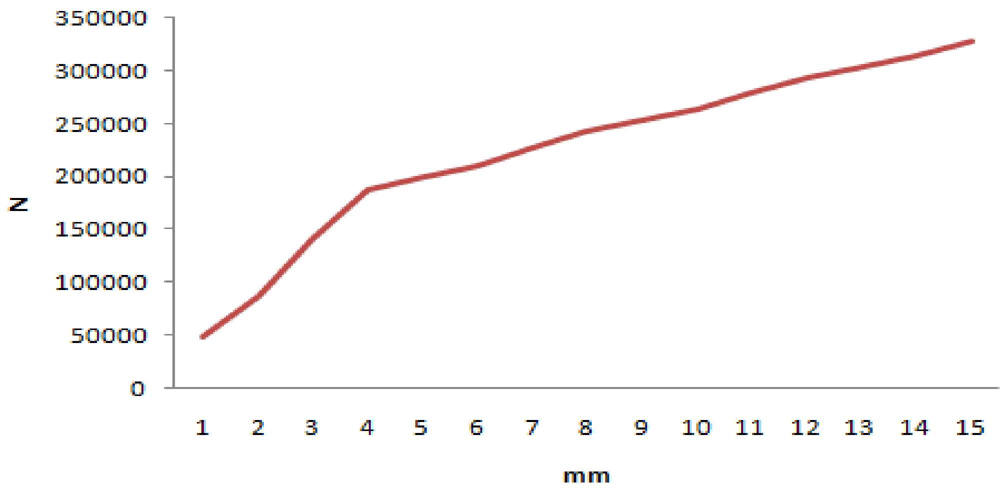

Figure 10: Displacement V/s Force graph for smooth surface condition between FRC and UHPC

Table 4: Temperature V/s Force values on UHPFRC

TEMPERATURE	FORCE
1	48685
2	86929
3.5	$1.4072e^{005}$
5	$1.8642e^{005}$
6	$1.9836e^{005}$
7	$2.0994e^{005}$
8.5	$2.2657e^{005}$
10	$2.4262e^{005}$
11	$2.5304e^{005}$
12	$2.633e^{005}$
13.5	$2.7845e^{005}$

15	2.9326e^{005}
16	3.0304e^{005}
17	3.1277e^{005}
18.5	3.2725e^{005}

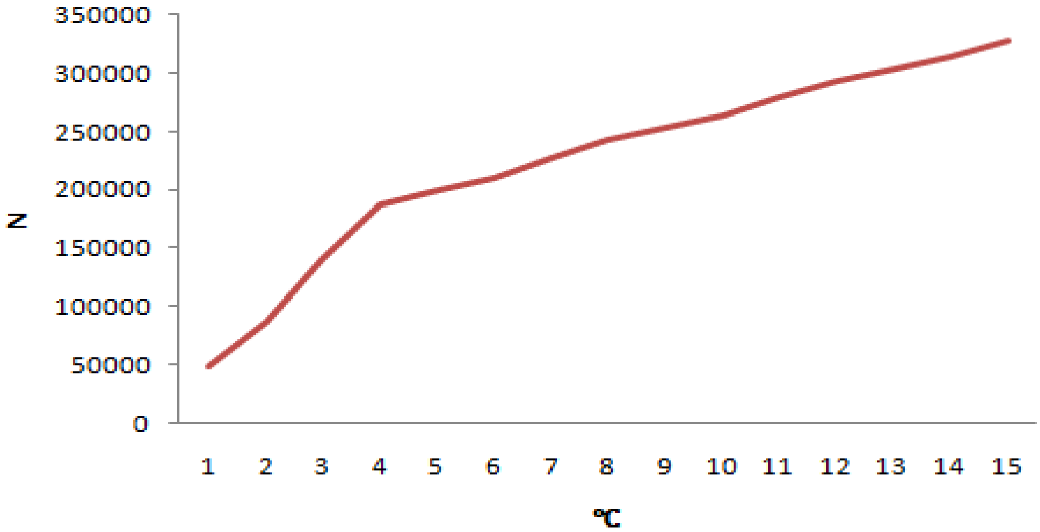

Figure 11: Temperature V/s Force graph for smooth surface condition between FRC and UHPC

1.3.2 UHPFRC Cube with rough surface condition:

1.3.2.1 Dimensions of sections of UHPC + FRC cube for analysis:

- MATERIAL No. 1 : FRC – M45
- DIMENSIONS – 150 X 100 mm
- MATERIAL No. 1 : UHPC – M130
- DIMENSIONS – 150 X 50 mm

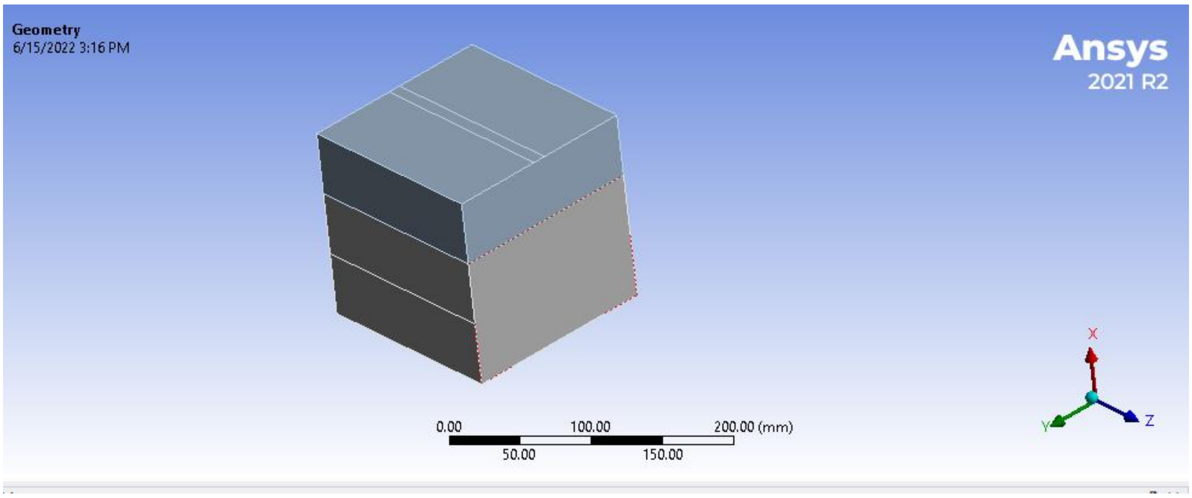

Figure 12: Geometry

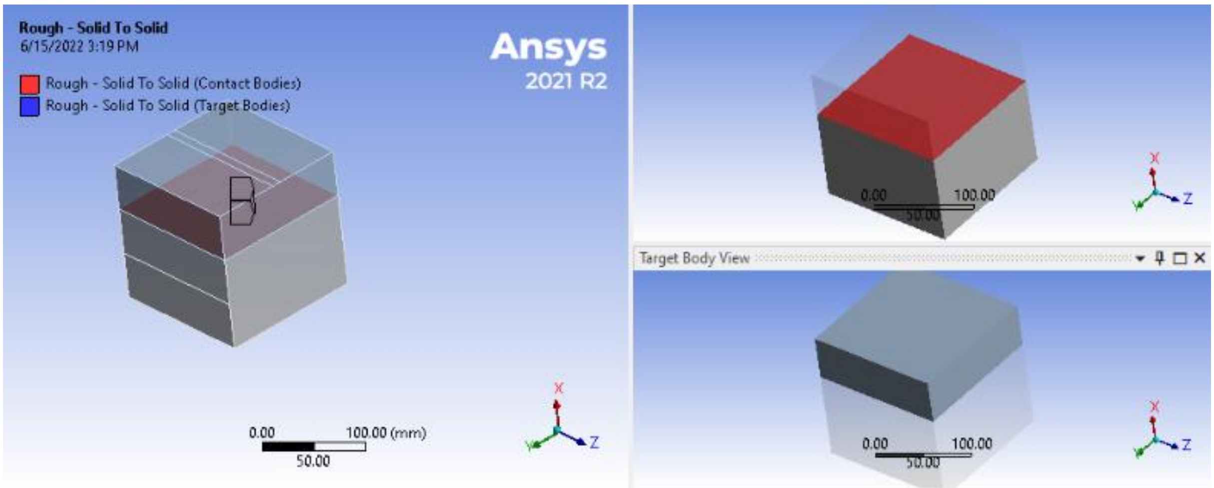

Figure 13: Model showing interfacial bond between FRC and UHPC with rough surface conditions

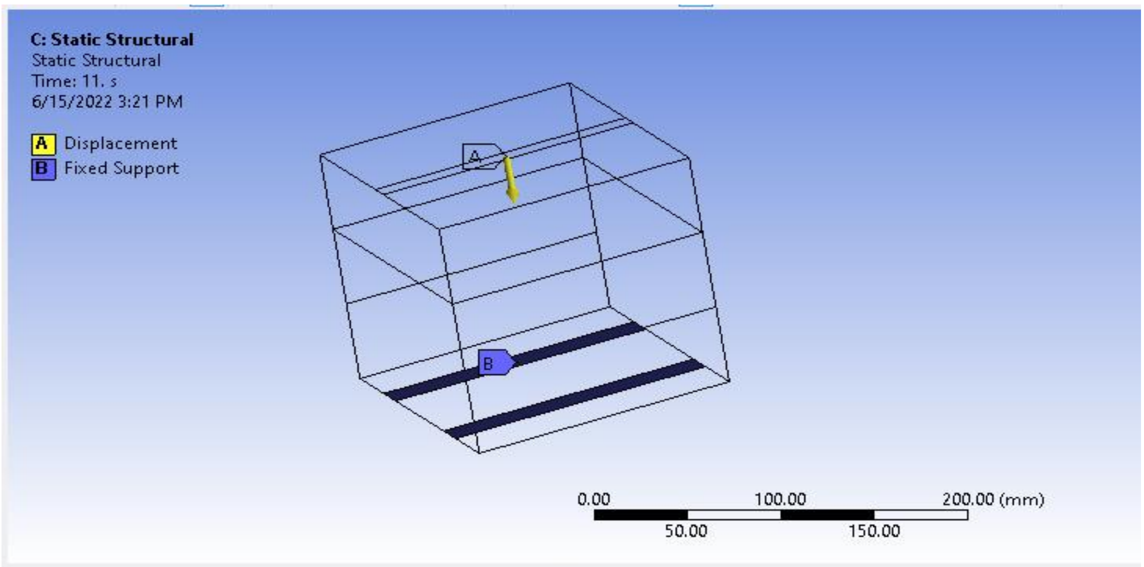

Figure 14: Support conditions

1.3.2.2 Results and discussion:

The results obtained are as follows: (Rough surface condition)

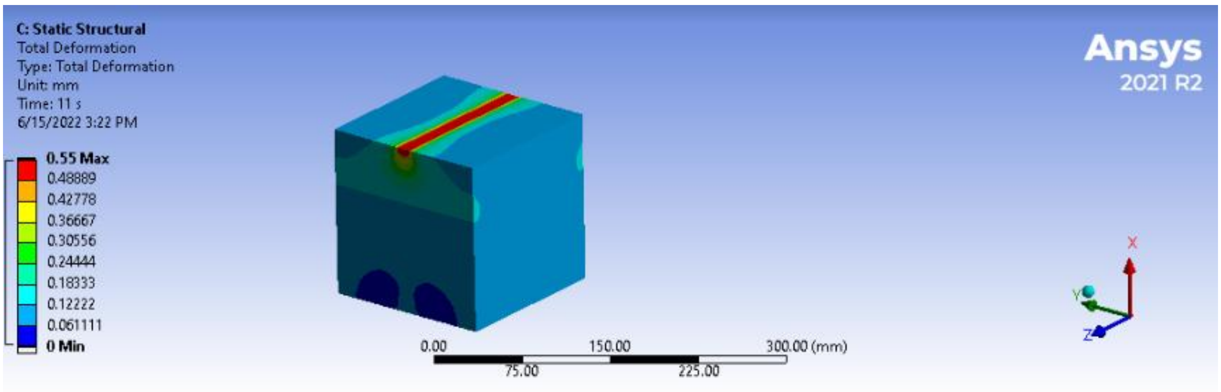

Figure 15: Total deformation pattern

From the figure obtained, maximum deformation occurred at the centre region where the load is applied and as it goes down, It is neutralized, and the load gets discharged. **(Maximum Value: 0.55 mm)**

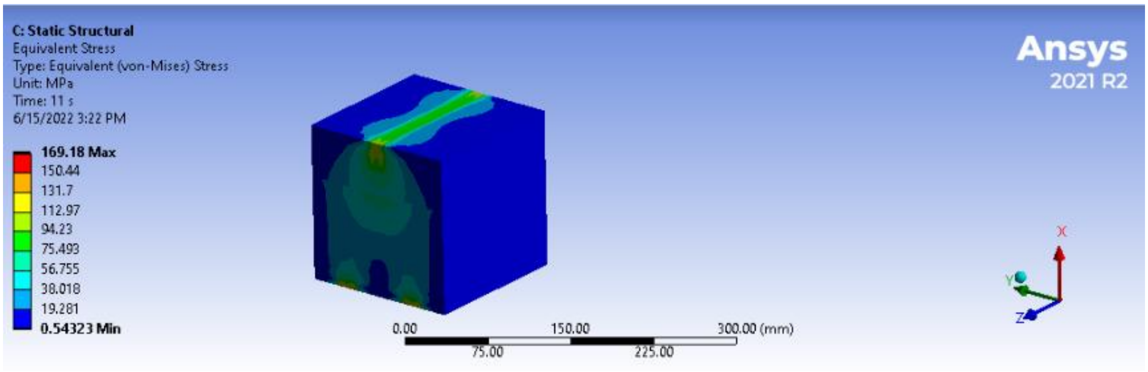

Figure 16: Stress variation

Equivalent (von misces) stress obtained after running the analysis. The stress in figure shows the crack patterns. **(Maximum value: 169.18 MPa)**

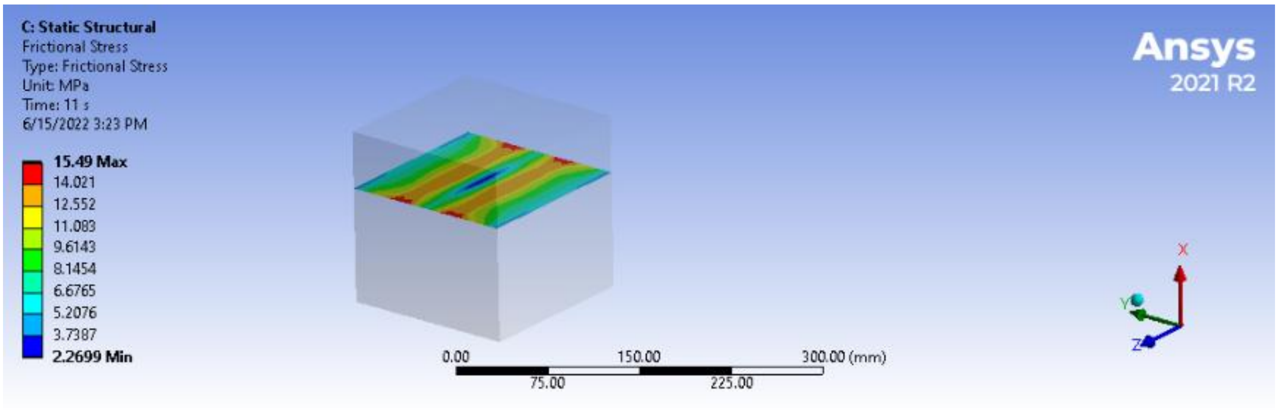

Figure 17: Frictional stress

In this figure, it is seen that load applied on the centre but it holds the maximum stress of 15.49 MPa on either sides where the red color is obtained at the interfacial layer of UHPFRC. That means the stress value is slowly decreased when it comes to center region of the interfacial layer that is where the blue color is shown. **(Maximum value: 15.49 MPa)**

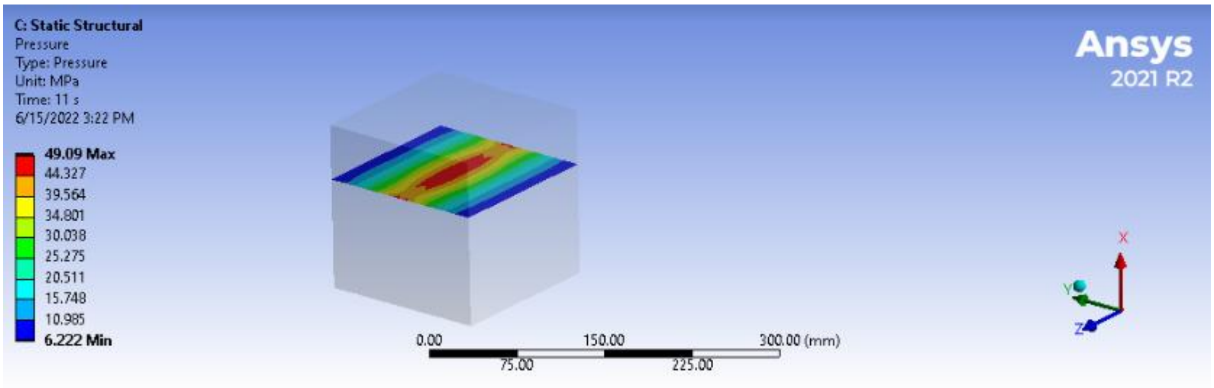

Figure 18: Pressure variation

Pressure is the resistive capacity of applied load. In this figure, the color changes from red to blue in +y direction to –y direction. i.e., pressure variation is maximum at the centre and gets slowly decreased when it moves to either sides of interfacial layer. **(Maximum value: 49.09 MPa)**

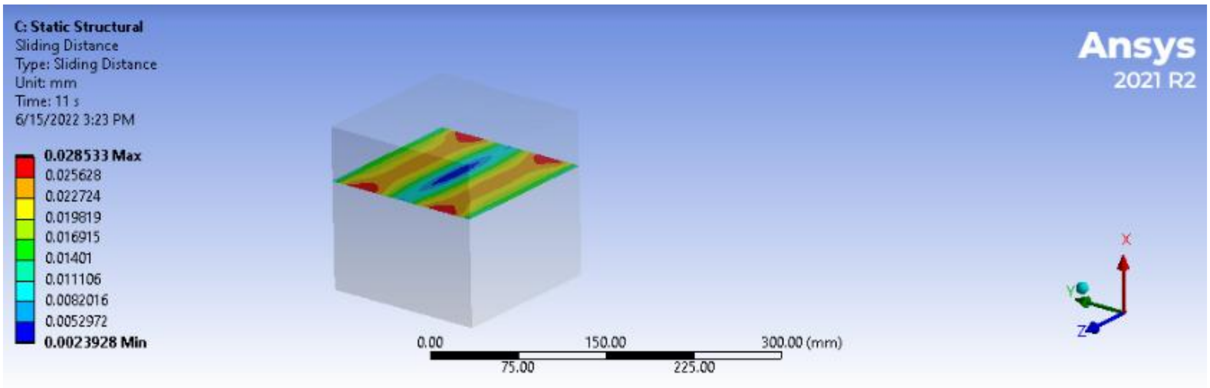

Figure 19: Sliding distance

The sliding distance is the slip of the contact elements as they are being debonde /separated from each other. In this figure, maximum value changes to minimum in horizontal direction. **(Maximum value: 0.028533 mm)**

Table 5: Displacement V/s force values on UHPFRC

DISPLACEMENT	FORCE
$-1e^{-002}$	47317
$-2e^{-002}$	64197
$-3.5e^{-002}$	$1.3656e^{005}$
$-5e^{-002}$	$1.8189e^{005}$
$-6e^{-002}$	$1.9356e^{005}$
$-7e^{-002}$	$2.0499e^{005}$
$-8.5e^{-002}$	$2.2139e^{005}$
-0.1	$2.3714e^{005}$
-0.11	$2.4738e^{005}$
-0.12	$2.5746e^{005}$
-0.135	$2.723e^{005}$
-0.15	$2.868e^{005}$
-0.16	$2.9637e^{005}$
-0.17	$3.0585e^{005}$
-0.185	$3.1995e^{005}$

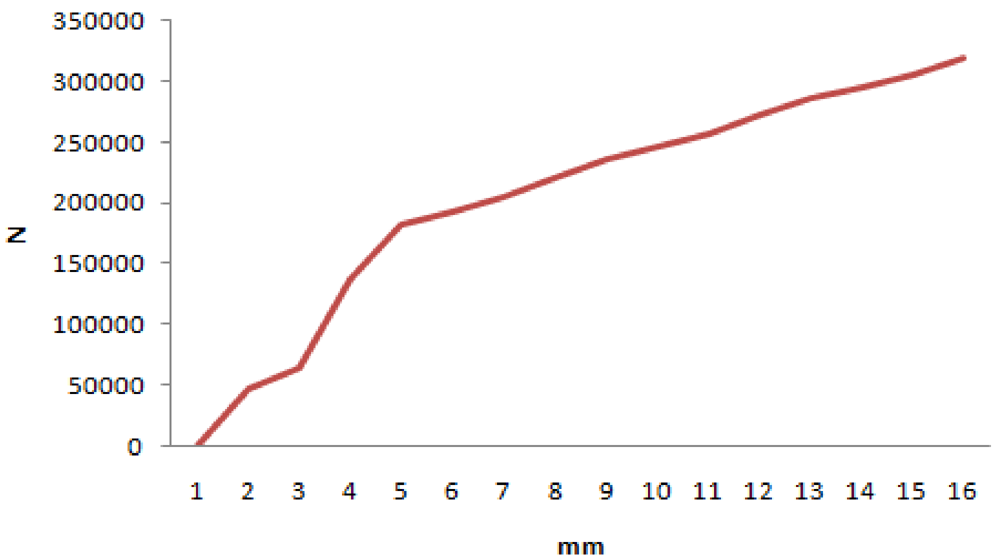

Figure 20: Displacement V/s force graph for rough surface connection between FRC and UHPC

Table 6: Temperature V/s force values on UHPFRC

TEMPERATURE	FORCE
1	47317
2	64197
3	$1.3656e^{005}$
5	$1.8189e^{005}$
6	$1.9356e^{005}$
7	$2.0499e^{005}$
`8	$2.2139e^{005}$
10	$2.3714e^{005}$
11	$2.4738e^{005}$
12	$2.5746e^{005}$
13	$2.723e^{005}$
15	$2.868e^{005}$
16	$2.9637e^{005}$
17	$3.0585e^{005}$
18	$3.1995e^{005}$

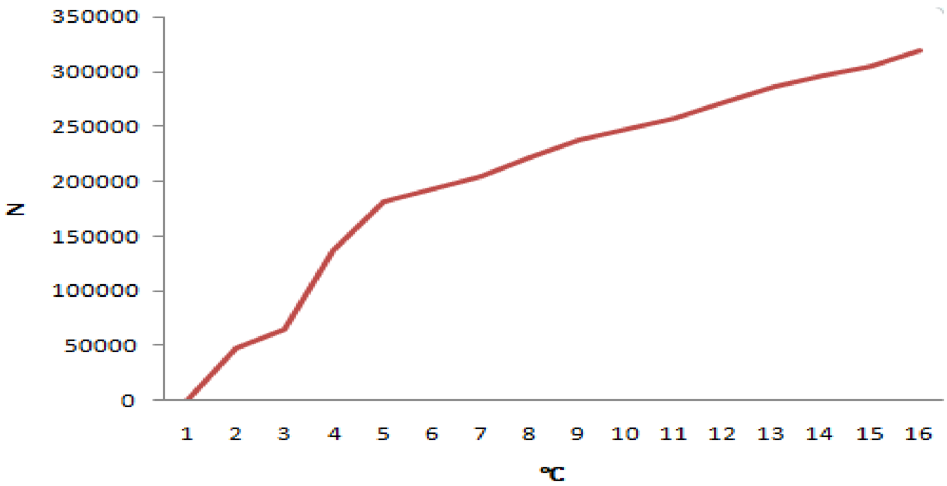

Figure 21: Temperature V/s force graph for rough surface connection between FRC and UHPC

II. CONCLUSION

Response of UHPFRC under two different surface connections are studied. Displacement V/s force graph and temperature v/s force graphs are analysed for both the smooth connection and rough connection. Following conclusion s are made on the basis of results obtained from this study of numerical modeling of UHPFRC with two different interfacial layers.

1. The stress values are more on center region. It is because the maximum normal stress occurs at the point of connection between FRC and UHPC, due to its greater rigidity and it will decrease and neutralize as it moves down.
2. Frictional stress is found more when it is given smooth connection between FRC and UHPC. So in that terms, rough connection works well with UHPFRC
3. By studying the pressure variation, it is found that rough connection is to resist more pressure, than that when compared to smooth connection.
4. The *sliding distance* is the slip of the contact elements as they are being debonded/separated from each other. The chances of debonding is high in case of smooth connection as the values obtained are more than the rough connection.
5. By analyzing the graphs, no major variation is found between both smooth and rough connection. Stress values are less by 1 MPa in rough connection when compared to smooth connection which is thereby found better.

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