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CHARACTERISATION AND COHESIVE ZONE MODELLING OF ADHESIVES AND BONE CEMENTS USED IN PROSTHESIS FIXATION SURGERIES

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Abstract

As there is a huge demand for the development and characterisation of proper Adhesives and Bone cements in the field of orthopaedic surgery which is used to fix the Prosthesis.We have taken this opportunity which is available in the field of orthopaedic surgery to characterise the mechanical properties of the Adhesive made of Cyanoacrylate and Bone Cements made of Poly Methyl Methacrylate(PMMA).The basic Static Testings like Tensile and Shear were made on the ASTM standard specimens of Cow Bones which is being fixed using the above mentioned Adhesive and Bone Cements.Almost 30 pairs of bones were machined in order to have the mechanical testings. A comparison study is made between the Adhesives and Bone Cements on it's efficiency of Adhering to the bone.A Cohesive Zone Model for the bones which is fixed by Adhesives and Bone cements is also developed in ANSYS.

Keywords: Prosthesis, Bone Cements, Poly Methyl Methacrylate, Cyanoacrylate

Introduction

The current surgical therapy of midfacial fractures involves internal fixation in which bonefragments with a suitable biocompatible adhesive remains highly attractive to orthopaedic surgeons. Despite decades of research, no suitable system that fully meets all the requirements for such an adhesive has not been identified. This article reviews the requirements and challenges of testing one common bone adhesive and two bone cement for fracture repair in knee replacement. The bone adhesives are generally classified into two groups: synthetic and biological adhesives. Earlier the synthetic adhesives include (polymethylmethacrylate) and related polymers, cyanoacrylates and polyurethanes. These adhesives are differentiated by relatively good mechanical properties. Yet they lack in few biodegradable and compatibility issues post-surgery. Recent adhesive systems based on lactide–methacrylate address these issues completely.Biological adhesives include fibrin based systems and they have good bio compatibility and biodegradability but lack the cohesive strength to have good adhesion to bone. The challenge to develop the adhesive systems themselves a further need is for greater consistency in the testing of adhesion to bone due to the stresses involved in the adhesive layer.

Furthermore, clear clinical need and vast market opportunity depicts there are no products available today as adhesives for bone. There are many bone cements but none of these claim any adhesive properties. Probably the best known of these products is polymethylmethacrylate(PMMA) bone cement that has long been used for the fixation of implants such as hip and knee replacements into bone. So, we decided to use the Cyanoacryalate adhesive and two bone cement named Palacos-R and Palacos LV depending upon their various properties.

Preparation of the specimens

Initially we planned to test the adhesives with the cut pieces of cow bone to plot the tensile and shear strength(specimens are made according to ASTM and ASME standards) of the adhesives and bone cements. The frozen parts of cow bone were prepared by allowing it to cool down to the room temperature and washed to clear the flesh and blood from the bone. As shown in the figure the bone was cut into rectangular shape in the approximate dimensions of (30*60) cm. The rectangular part was divided into segments with the dimensions of (10*20) cm for each individual specimen uniformly with the permanent marker. After these operations the bone specimen is made to hold in the cutting machine. The cutting machine was fixed with the abrasive tool to cut the bone specimens to reduce the tension between the bone surface and cutting tool. It also prevents from the breaking of bone during the cutting process.We continued this process until we got totally 15 individual specimens for tensile test and 15 individual specimens for shear test. Tensile test specimens were separated and each specimen was exactly divided into two-half by marking in the middle of the specimen. The midpoint of the first half was marked using the Vernier caliper and the same procedure was continued on the other half of the specimen. The midpoint was marked to drill hole at those marked points to hold the specimens in the universal testing machine. A 1.6 mm drill bit was used to drill the hole in the specimen. Finally, after plotting all the marking on the individual specimen it was cut in the midpoint and those two pieces are from the single specimen. The cut specimen is rubbed with the swiss-made emery sheet to produce uniform adhesive layer. From the figure you can seethat the cut specimen and they were marked at cutting surface to remember where the adhesive should be applied during the testing process. The exact procedure was followed for all the remaining tensile specimens and marked in their cutting surface. For the shear specimens it included the same process but the last task of cutting the specimen was not necessary as it was the shear test.

Application of adhesives

Cyanoacrylate is the most extensively studied group of adhesives for bone, and other tissue based adhesive applications. The adhesion of a wide range of cyanoacrylates to bone under varying storage conditions and times have been reported successful. Cyanoacrylates have been used extensively in wound closure and there are several commercial products that exists, no product has emerged with great success in the orthopaedic arena. Cyanoacryalate has the stability upto 6 weeks but later there was in adequate for successful healing. The specimens were tested by cleaning the adhesive surface with a PBS solution for ten minutes to eradicate any infections and to produce a wet condition on the surface for the adhesive to stick to the bone specimen. A little drop of cyanoacrylate was applied on the surface carefully and evenly spread all over the surface. The part "b" of the same specimen is placed on top of the adhesive surface coherently. This process is carried out very rapidly because the cyanoacyralate gets attached to the surface at a faster pace. Simultaneously, the adhesive is applied to all the specimens at the same time and prepared for the tensile and shear test. From the figure we can see the specimens before and after the application of adhesives and the difference between them.

Palacos is bone cement which is successfully used to anchor artificial knee joints especially. It fills the free area between the prosthesis and the bone which plays a major role of an elastic zone. The bone cement must absorb the forces acting on the hip to ensure the artificial implant remains in place over the long term. It had excellent fatigue strength compared to other bone cements and the risk ratio was less in palacos bone cement and it has excellent bonding strength between the bone and the implant. The green color bone cement improves the vision from the bones. We applied the bone specimens with palacos bone cement to proceed with the tensile and shear test and promising results were found.

Palacos LV is a similar bone cement with the addition of zirconium dioxide in the cement composition. It is suitable for small and medium sized joints. As the name suggests it has low viscosity which reduces the tedious work involved in applying the bone cements on the specimen surface. Both the cements contain the same properties and results are obtained from the procedure.

Fracture Mechanics(cohesive and adhesive zone modal)

The Crack Tip Opening Displacement(CTOD) model for the bone along with Adhesives and Bone Cement is developed.

New material library is created in ANSYS version 18 by obtaining data like Young's Modulus, density and Poisson's ratio for adhesives and bone cements from CES-Edupack Software.

The density of Cow's femur is found to be 1.32e ^ 3kg/m ^ 3 and Young's Modulus is 3.75e ^ 9Pa.

The Density of Bone cement is found to be 1.22e ^ 3kg/m ^ 3 and Young's Modulus is 3.8e ^ 9Pa.

The Poisson ratio of bone and Adhesives lie between the range of 0.30 to 0.45.

The semi elliptical Crack with tetrahedron meshing is developed in the region between bone and Adhesives and it's mode of fractures(K1,K2,K3) and J-Integral Values are studied by applying a pressure of 1000Pa on the top Surface of the bone.

The fracture mechanics design is only made for the optimum bone geometry.

Conclusion

- The Bone Cements is comparatively working better in the fixation of the bones.
- The Sterility and Wetness of the bone plays a major role in the Adhering strength of the Bones.

- The Surface finish of the adhering surfaces plays an important role in fixation.
- Low viscous Bone Cement gives a better Adhering Strength.
- Cyanoacrylate produces less exothermic reaction than the Poly Methyl Methacrylate
- Curing time needed for the bone Cements is much higher than the Adhesives.
- Bone cements needs vigorous Mixing of the polymers.

Figures:

Figure 1:**For Bone without any fixation**

a-Mode 1 Fracture

b-Mode 2 Fracture

c-Mode 3 Fracture

d-Strain energy release rate(J-integral)

Figure 2:**For Bone stuck with Bone cements(Palacos and Palacos-LV)**

a-Mode 1 Fracture

b-Mode 2 Fracture

c-Mode 3 Fracture

d-Strain energy release rate(J-integral)

Figure 3:**For Bone stuck with Adhesive(cyanoacrylate)**

a-Mode 1 Fracture

b-Mode 2 Fracture

c-Mode 3 Fracture

d-Strain energy release rate(J-Integral)

Figure 4:

a-Initial Cow's Femur

b-Abrasive Cutter for Bone

c-Grinding to get proper surface finish

d-ASTM specimen of bone

e-Testing of stuck bone

Tables

Table 1- Consists of Tensile and Shear Stress of Bones stuck with adhesives and Bone cement.

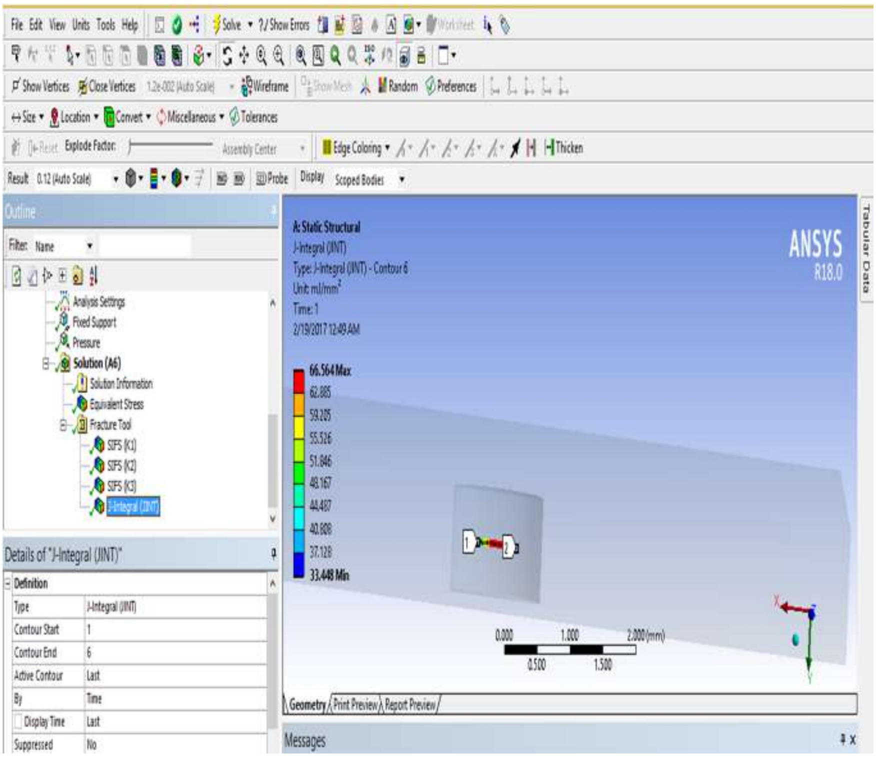
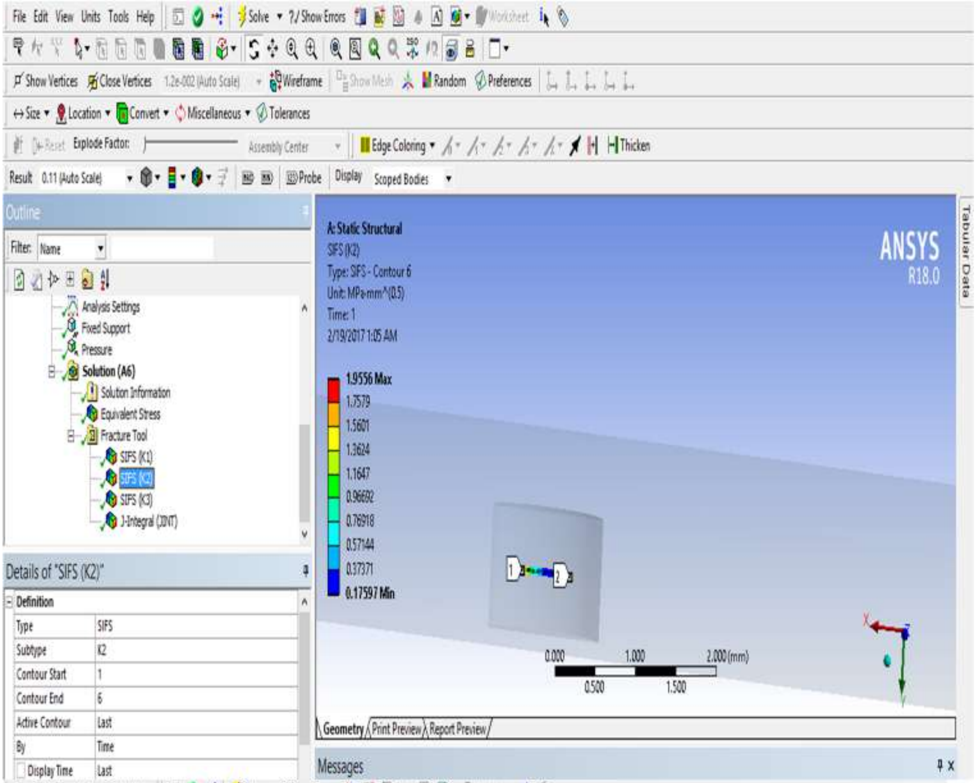


Table 1

S.NO	ADHESIVE	SPECIMEN NUMBER	TYPES OF TESTING	AREA(mm^2)	TENSILE FORCE(N)	SHEAR FORCE(N)
1	Cyanoacralite	1	tensile	71.5 mm2	50	
2	Cyanoacralite	2	tensile	60.5 mm2		
3	Cyanoacralite	3	tensile	49.5 mm2	129.47	
4	Cyanoacralite	4	tensile	57.5 mm2		
5	Cyanoacralite	5	tensile	42.5 mm2	166.39	
6	Palacos LV	6	tensile	73 mm2	340.17	
7	Palacos LV	7	tensile	35.5 mm2	74.67	
8	Palacos LV	8	tensile	74.5 mm2		
9	Palacos LV	9	tensile	48.5 mm2	111.31	
10	Palacos LV	10	tensile	65.5 mm2	435.64	
11	Palacos	11	tensile	56 mm2	219.8	
12	Palacos	12	tensile	64 mm2	104.5	
13	Palacos	13	tensile	45 mm2	361.49	
14	Palacos	14	tensile	61.5 mm2	358.98	
15	Palacos	15	tensile	55 mm2	262.46	
16	Cyanoacralite	1	shear	37.5 mm2		256
17	Cyanoacralite	2	shear	34.5 mm2		43
18	Cyanoacralite	3	shear	29.5 mm2		178.8
19	Cyanoacralite	4	shear	52.5 mm2		428.5
20	Cyanoacralite	5	shear	38.5 mm2		156.8
21	Palacos	6	shear	42.5 mm2		69.1
22	Palacos	7	shear	47 mm2		29.6
23	Palacos	8	shear	37.5 mm2		179.7
24	Palacos	9	shear	49.5 mm2		446.2
25	Palacos	10	shear	51 mm2		144.7
26	Palacos LV	11	shear	49.5 mm2		109.8
27	Palacos LV	12	shear	49 mm2		40.2
28	Palacos LV	13	shear	49.5 mm2		318.5
29	Palacos LV	14	shear	46.5 mm2		310.4
30	Palacos LV	15	shear	48.5 mm2		58.6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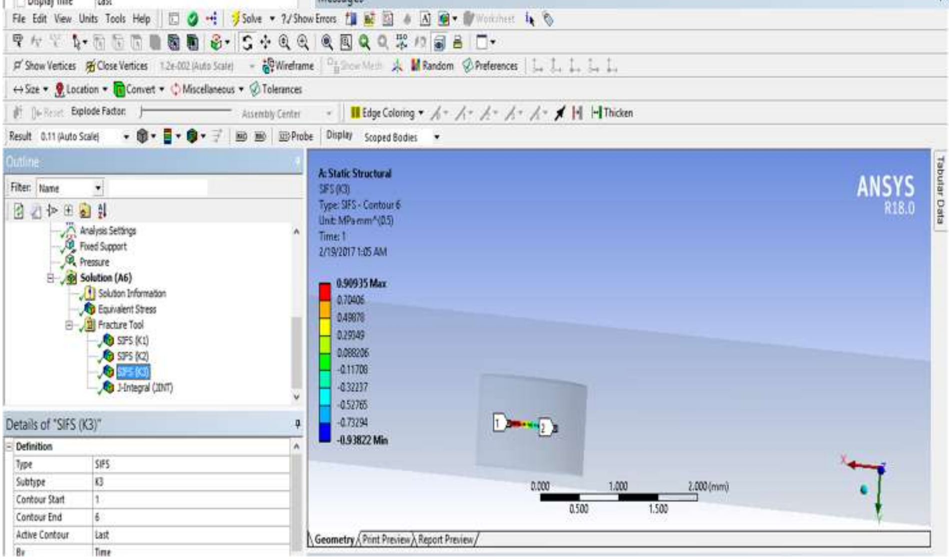
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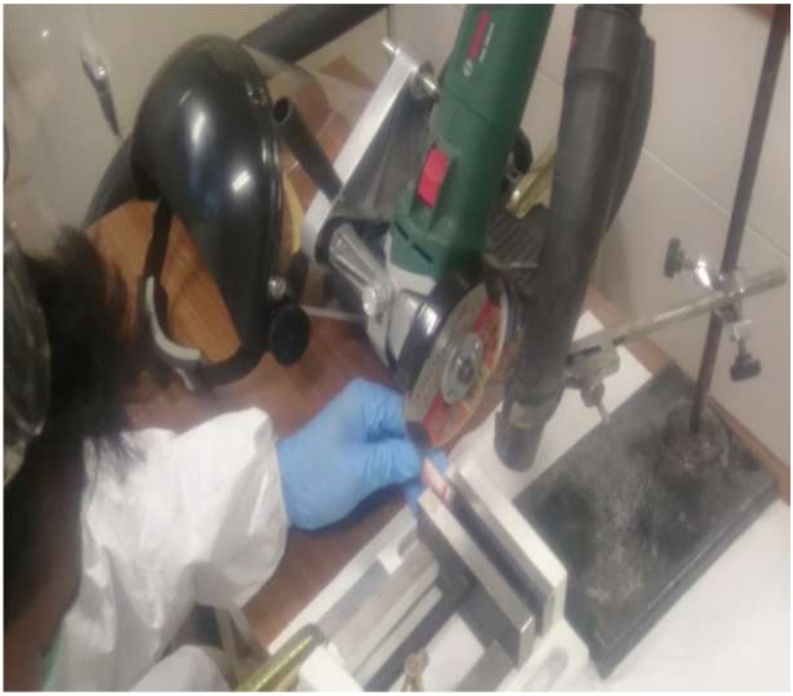

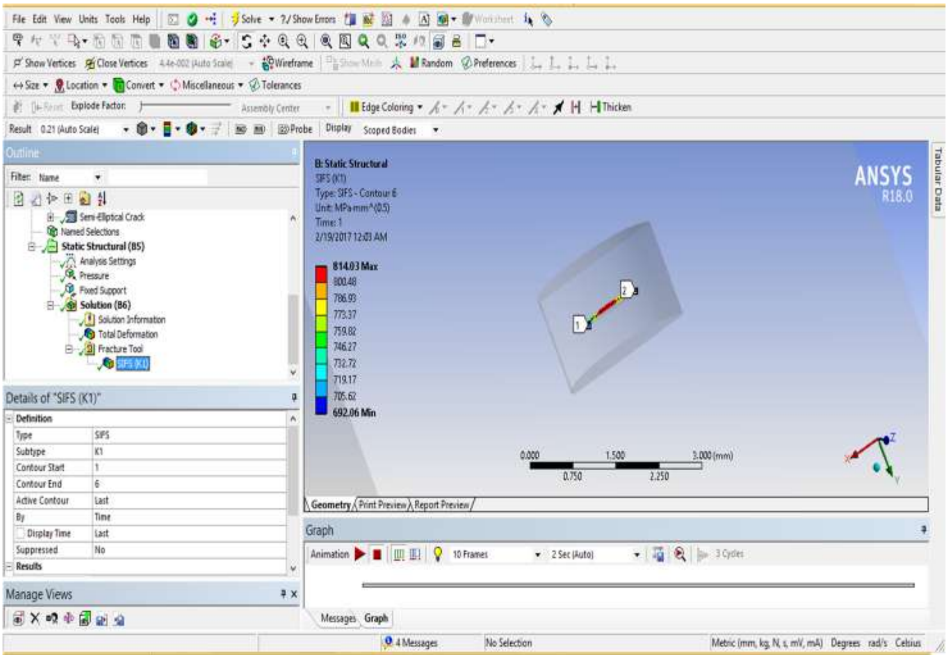
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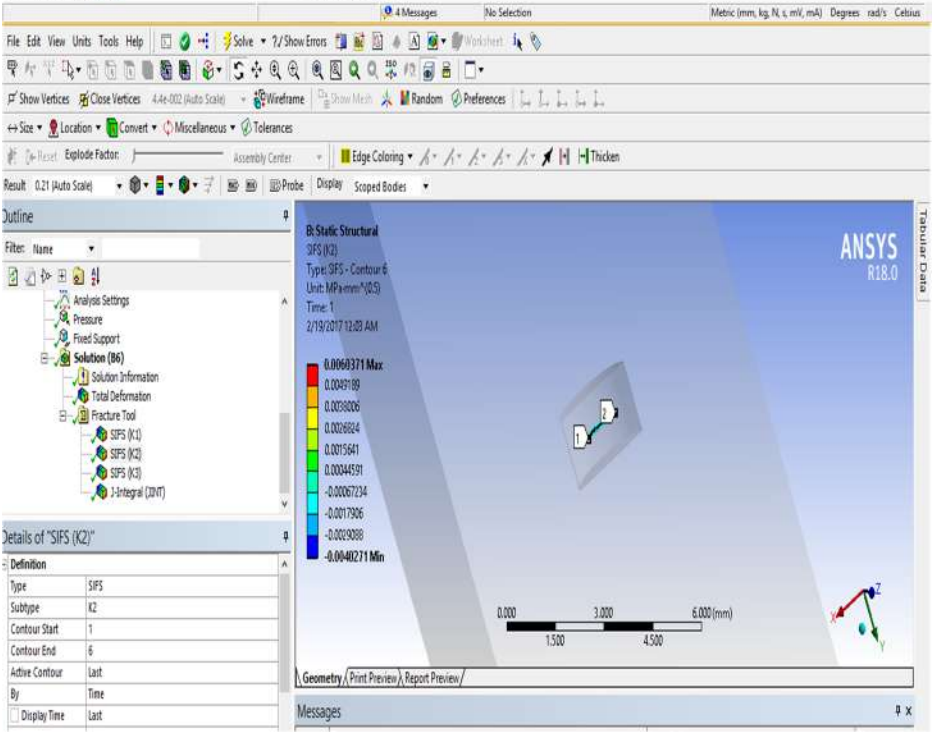
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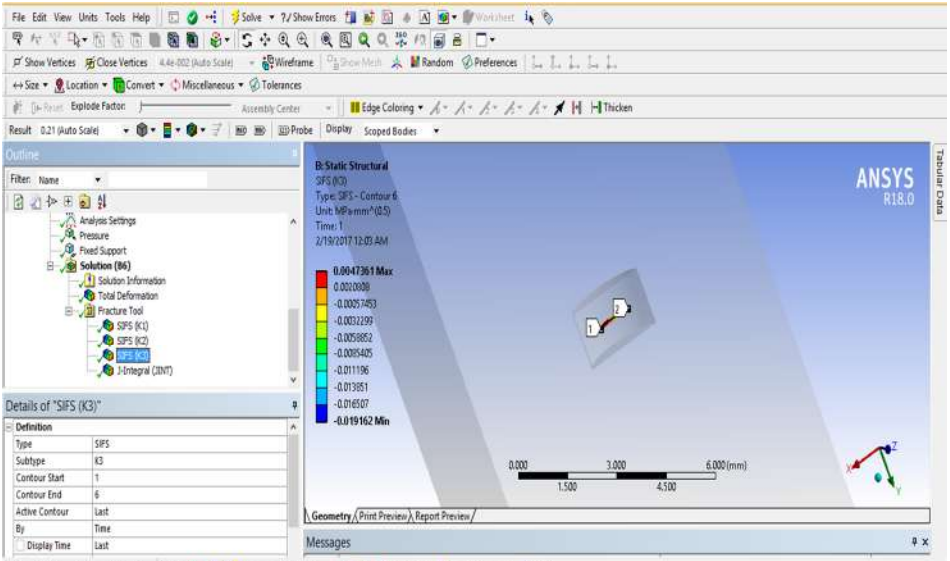
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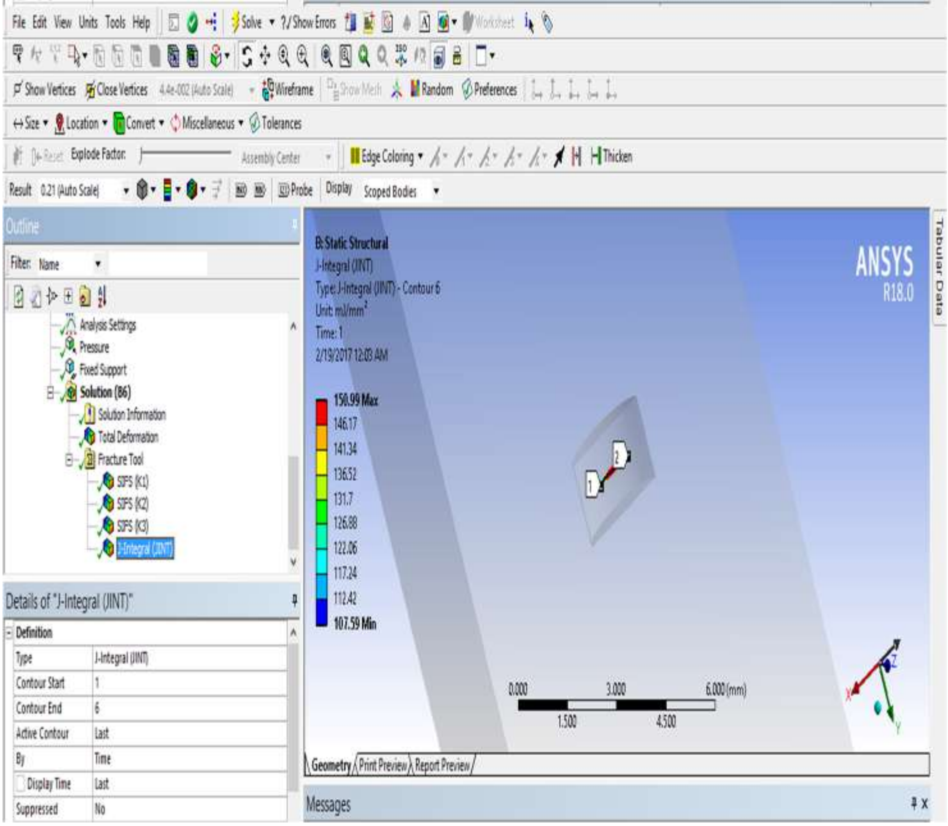
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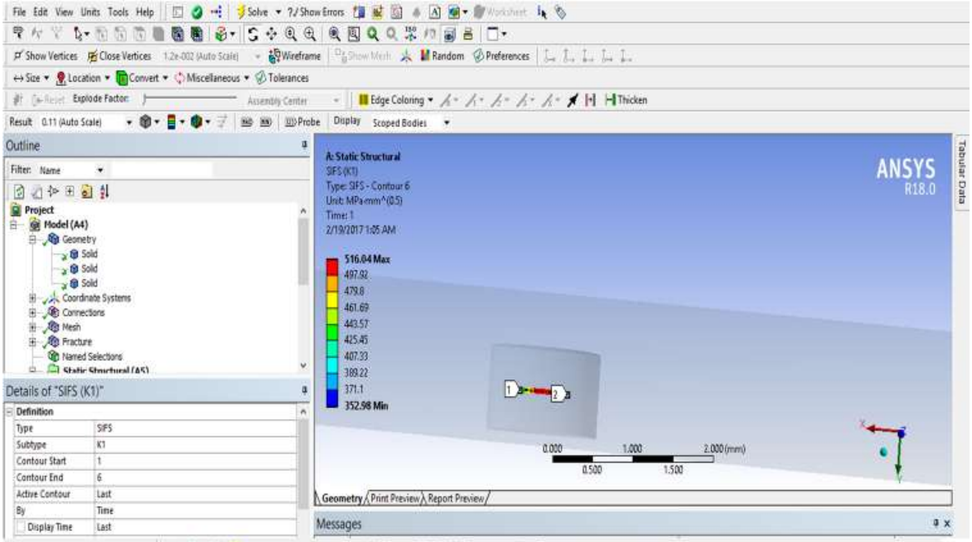
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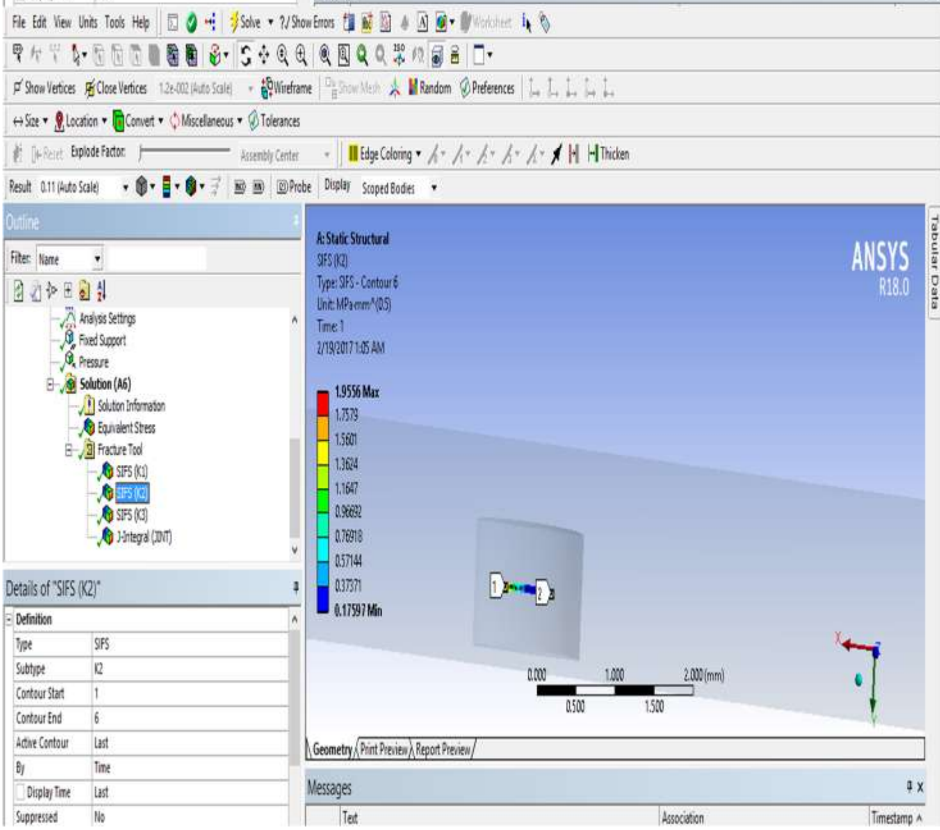
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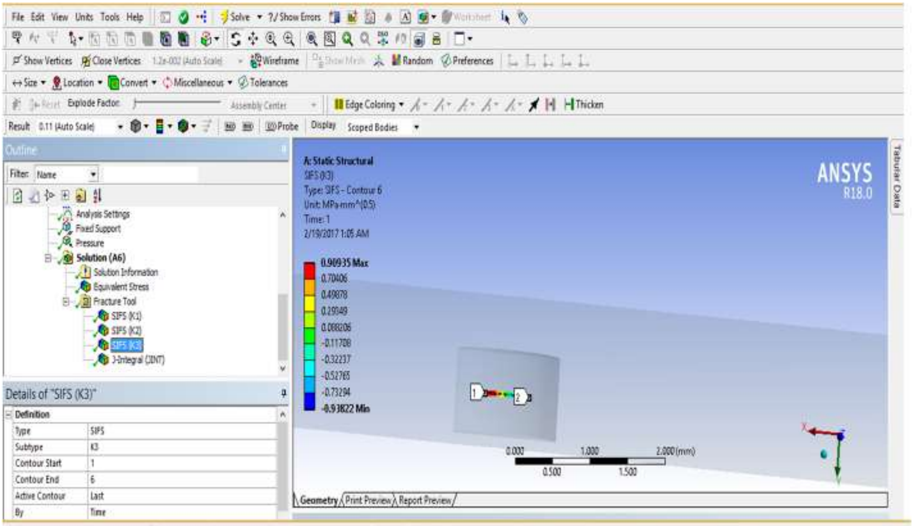
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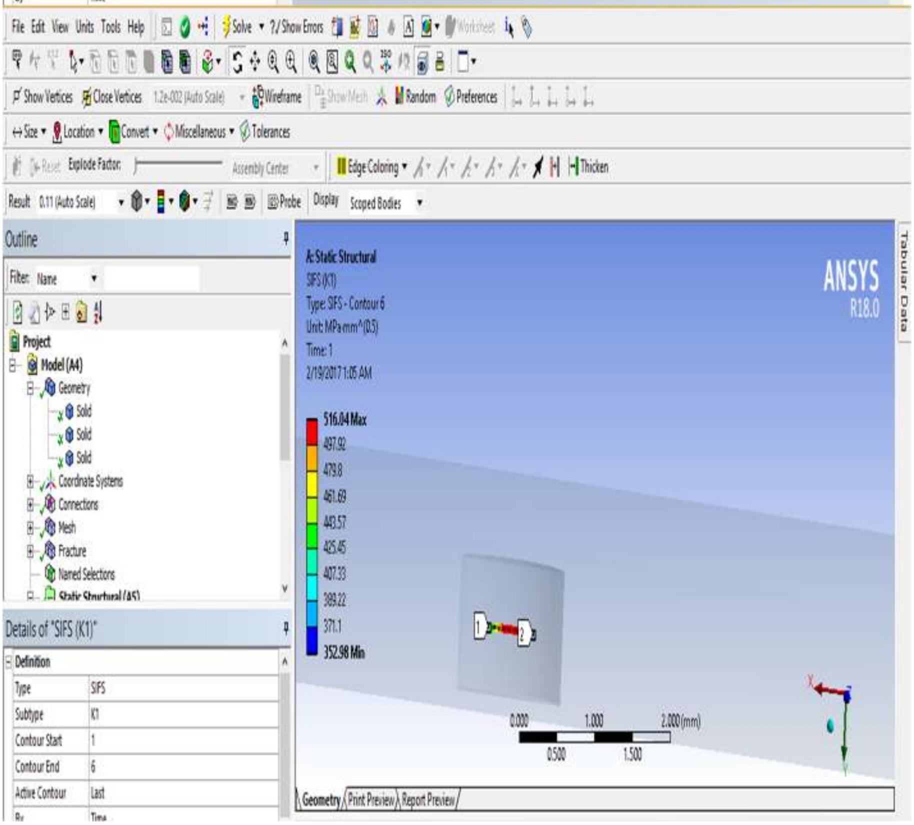
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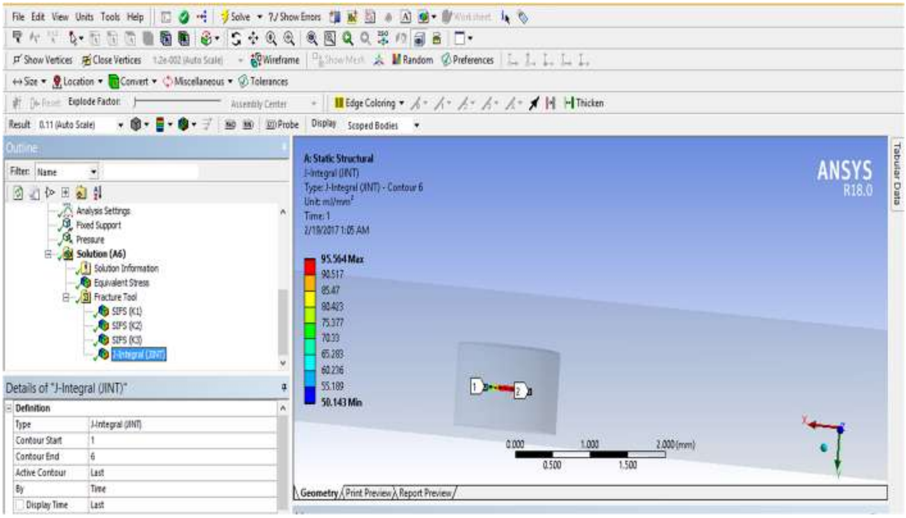

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