SiC/SiC RADIATION DAMAGE ASSESSMENT

(A Progress Report)

H.D. Shatoff, GA, S. Majumdar, ANL, C. Wong, GA

**(Consultations with G. Youngblood of PNNL,
N. Ghoniem of UCLA
E. Lara-Curzio, L. Snead and S. Zinkle of ORNL)**

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BACKGROUND

- **Fusion Neutron Radiation Damage effects on Thermal Conductivity and Mechanical Properties are critical issues for the fusion power reactor application of SiC/SiC composite material.**

- **Thermal Conductivity improvements are being demonstrated by fiber purity improvement and fabrication process. The combination of fiber coating and carbon fiber are being investigated for further improvement. With the single-fiber model G. Youngblood of PNL investigated transverse k_{th} improvement by modeling and compared results to experiments.**

- **Youngblood is also continuing the single-fiber modeling of stress-strain effects, by the method of Edgar Lara-Curzio with the inclusion of creep effects. This approach allows the inclusion of changes in the properties of the fiber, coating and matrix materials. Coupling with the work by Ghoneim, et al., basic properties projection is absolutely necessary.**

- **In parallel H. Shatoff of GA introduced the analysis of bond failure with friction by using the well-established ANSYS FE analysis code for the single fiber assessment. 2-D results are presented. In the future, mechanical and thermal effects can be coupled in 3-D.**

- **Initial benchmarking is to perform calculations for a 5° sector of a circular specimen constrained to 2-D motion and compare results with the push-pull test results.**

  (The single-fiber geometry is taken from the paper by S. Majumdar, D. Singh and J P. Singh, "Analysis of pushout tests on an SiC-fiber-reinforced reaction-bonded Si_3N_4 composite," Composites Engineering Vol. 3 No 4, 1993).

GOAL

To assess the SiC/SiC composite lifetime
(Can we reach the fluence goal of 3% burn-up i.e. 15 MW.a/m^2 ?)

DESCRIPTION

- **The ANSYS model contains both friction contact elements and bond contact elements. The bond contact elements are scanned for normal tension and shear stress levels and dropped when the allowable stress is exceeded.**

- **APDL coding was written to scan the stresses in the bond elements and drop them if failed.**

- **The analysis is 2-D, even though 3-D finite elements are used in preparation for 3-D analyses.**

GENERAL APPROACH

- **Develop model and benchmark available results with SiC fiber and Si_3N_4 matrix composite and compare to test results. (This presentation)**
- **Propose to extend and benchmark results with SiC/SiC composite and compare to the model being developed by Youngblood. SiC/SiC pushout test results to be reviewed by Majumdar.**
- **Evaluate cases with fiber/coating/matrix properties with inputs from Ghoneim, et al., before and after irradiation.**
- **ANSYS model could possibly also cover the property of effective thermal conductivity of the single fiber composite.**
- **We would also propose a scenario for SiC/SiC property improvement when appropriate.**
- **This modeling task is proposed as an R&D item under the APEX program.**

Input SiC/Si_3N_4 composite properties and assumed inputs used for this assessment.

(Most of the following data are from Majumdar's paper.)

Elastic Modulus	Matrix	310 GPa
	Fiber	400 GPa
Coefficient of thermal expansion:		
	Matrix	$3.3*10^{-6}$ /°C
	Fiber axial	$4.7*10^{-6}$ /°C
	Fiber trans	$2.63*10^{-6}$ /°C
Fiber volume fraction		32.3 %
Diameter of fiber		0.15 mm
Diameter of matrix		0.2639 mm
Thickness of specimen		1.23 mm
Assumed interface friction		0.16 or 0.32
Assumed interface bond strengths		normal 20 MPa
		shear 10 MPa

Loadings:	
Initial thermal loading	1350° C drops to 20° C (100 load steps were taken)
Push of fiber	between 0.05 and 0.10 mm along axis (0.001 mm push increment per step)

PROCEDURE

- **The thermal shrinkage of the matrix onto the fiber was computed and large thermal shear stresses were induced between the fiber and matrix, which 'broke' the bond contact elements.**

- **Only friction shear remained at the end of the thermal shrinkage.**

- **Then the fiber end was pushed axially while the matrix was constrained by a back contact surface.**

- **The push force and displacement were plotted.**

RESULTS

- Figures 1 and 2 show the push force versus displacement for friction values of 0.16 and 0.32, respectively. Breakthrough loads of 8.6 and 16.5 NT, respectively are shown. The results compare quite well with the test data presented in Majumdar's paper, test results showing the loading ~10-14 NT. i.e. experimental friction can then be approximated.

- The finite element grid consists of 1499 nodes and 826 elements as shown in figure 3.

- The thermal shrinkage is illustrated in figure 4 for the 0.16 friction factor case. This is a plot of the axial displacement at the end of the thermal loading. The fiber shrinks axially more than the matrix.

- Figure 5 shows the 0.05 mm push of the fiber through the matrix.

- The stresses on the friction contact elements are shown. The frictional shear stress is shown in figure 6 and the normal pressure stress in figure 7.

- Figure 8 shows a close-up of the normal pressure stress at the end being pushed. The maximum normal pressure occurs at this end and of course the pressure drops to 0 where the interior of the matrix is exposed.

Fig. 1 Push Force Vs Axial Displacement (Friction = 0.16)

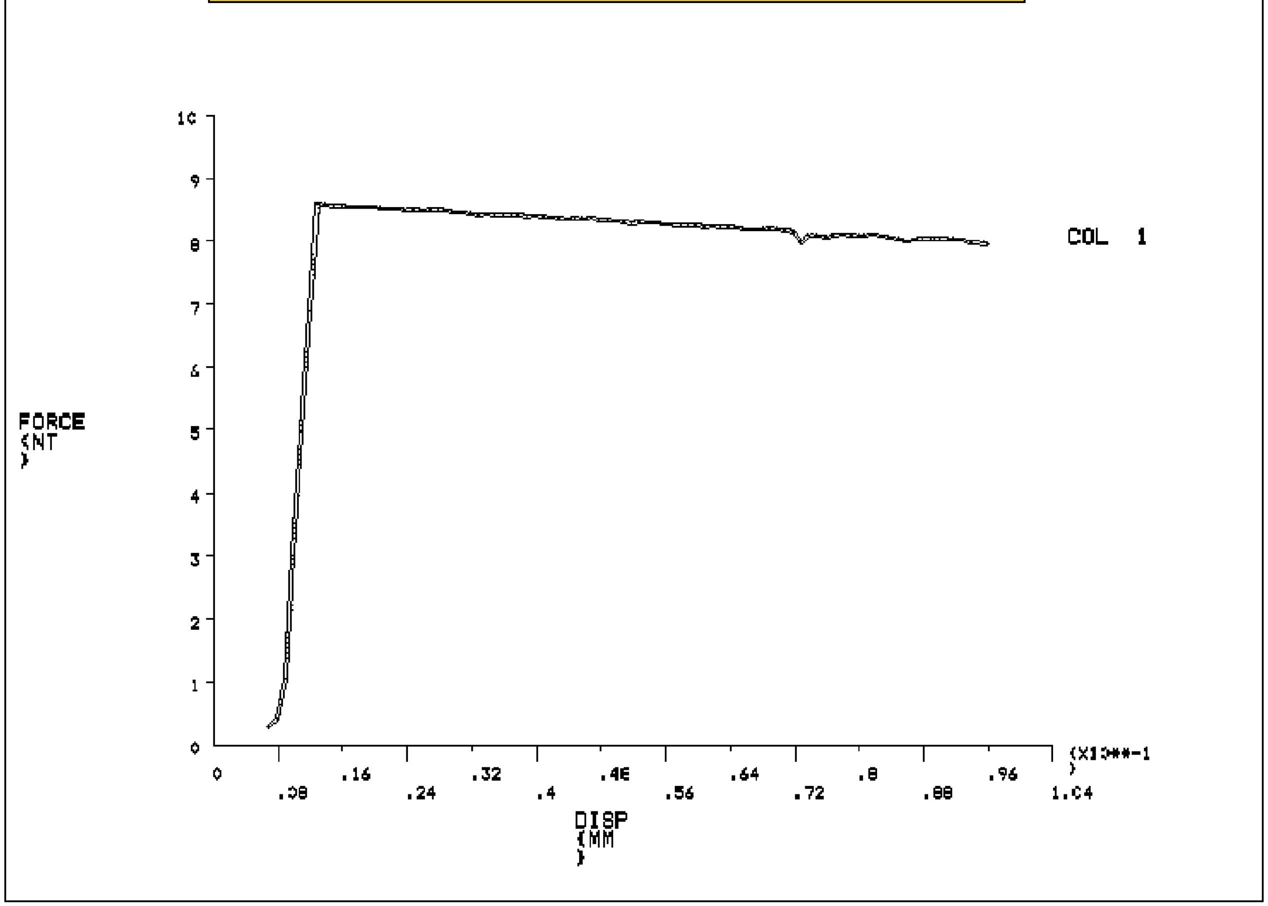
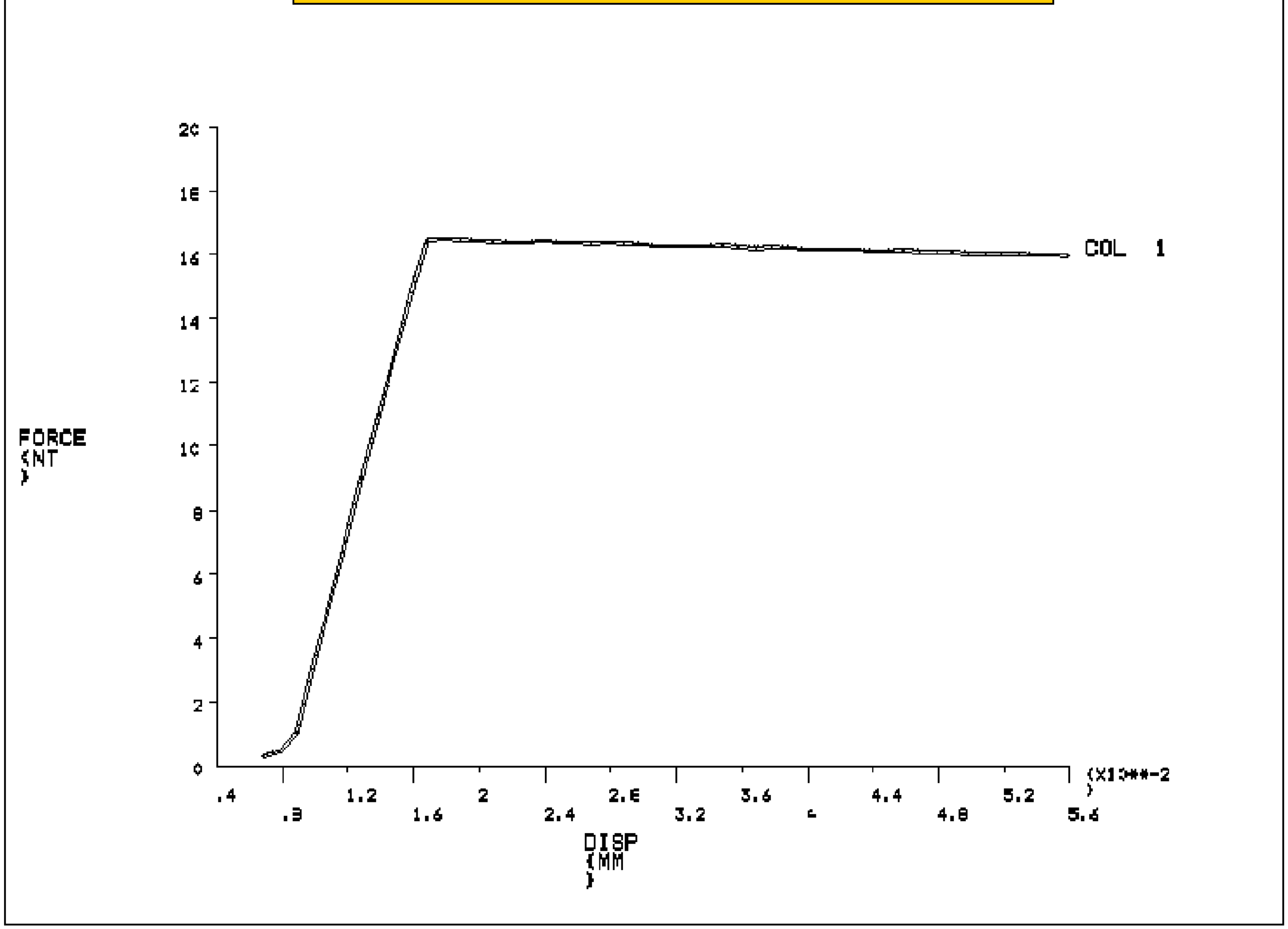


Fig. 2 Push Force Vs Axial Displacement (Friction = 0.32)



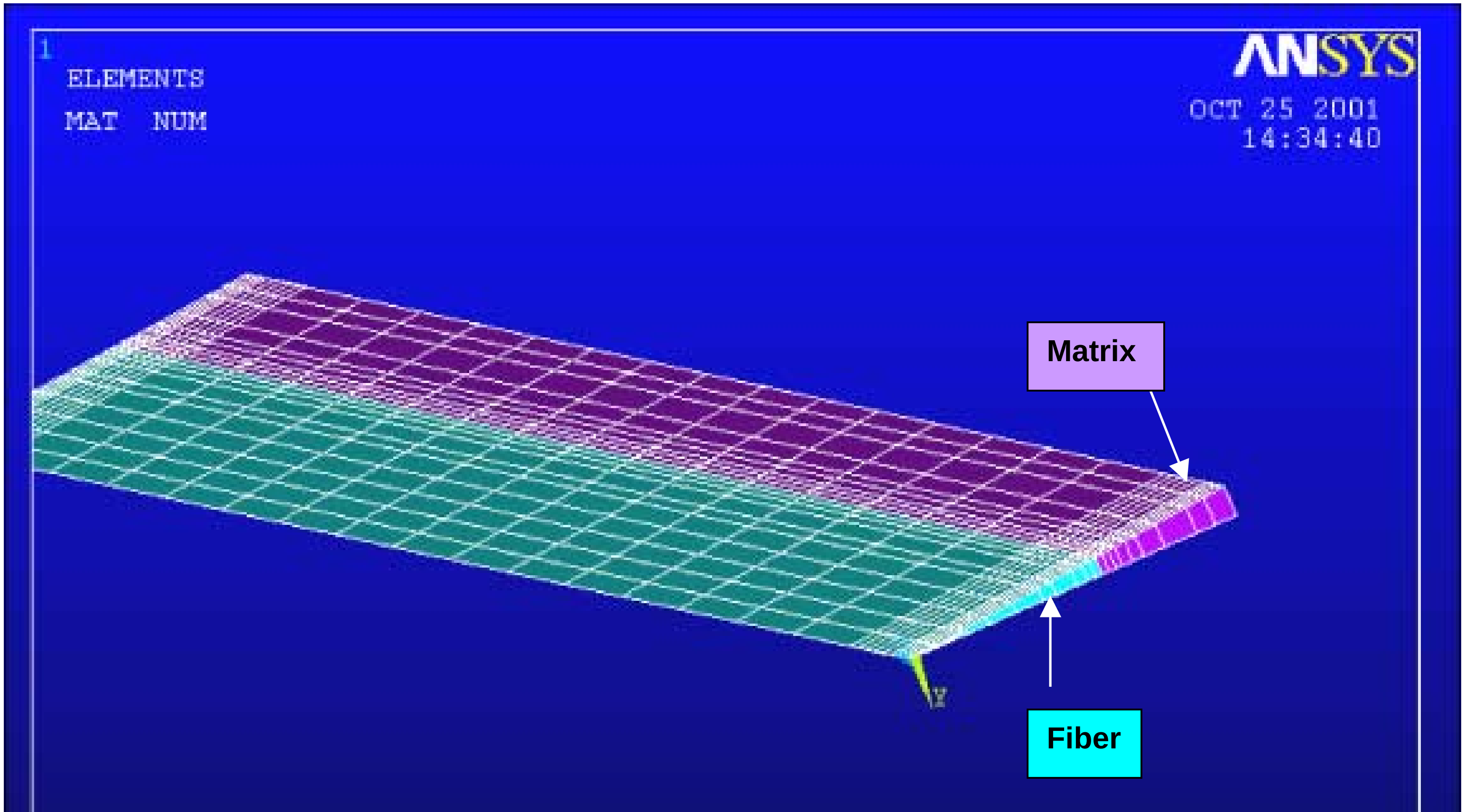


Fig.3 5° Finite Element Grid Consists of 1499 nodes and 826 Elements

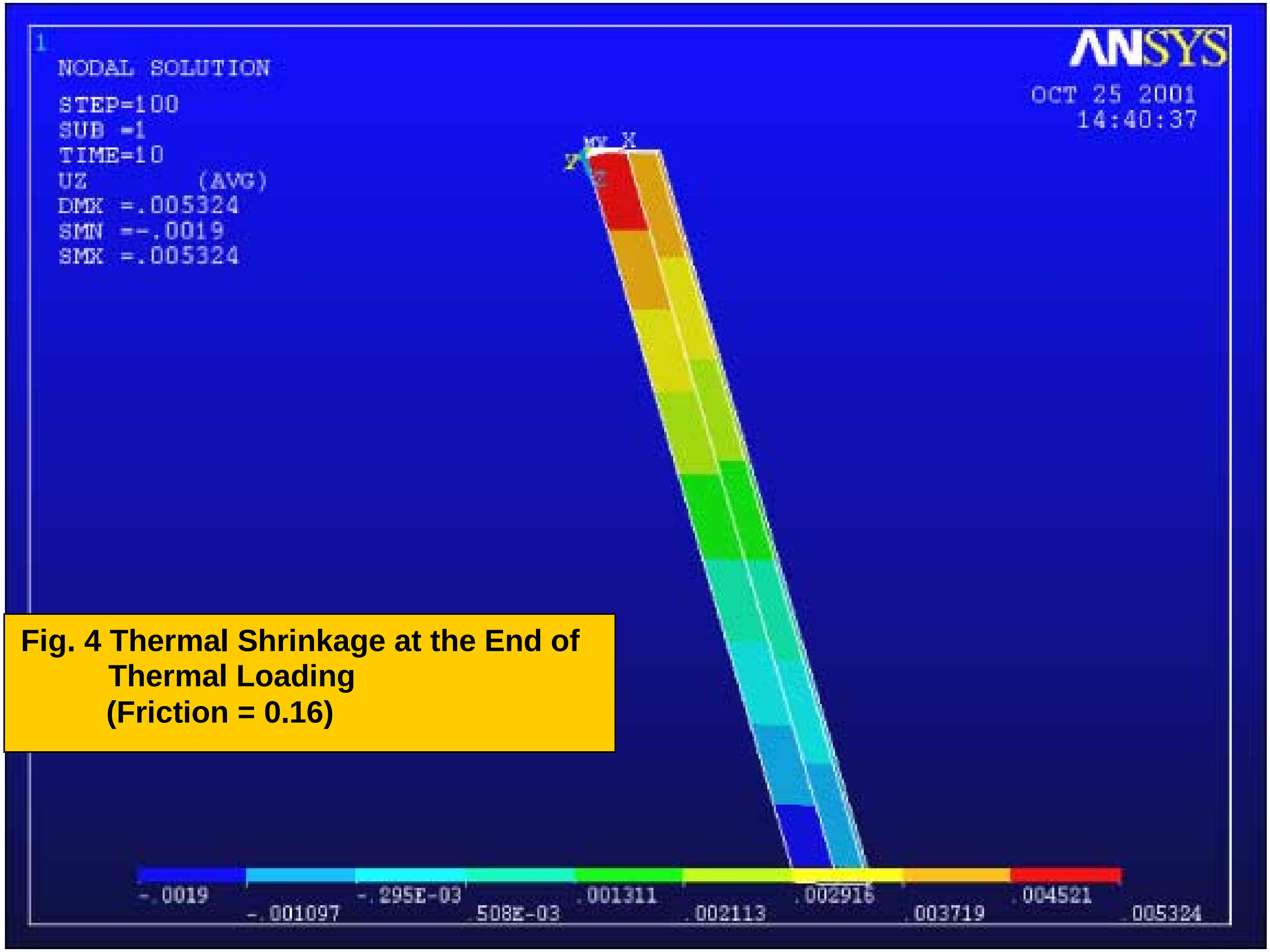


Fig. 4 Thermal Shrinkage at the End of Thermal Loading (Friction = 0.16)

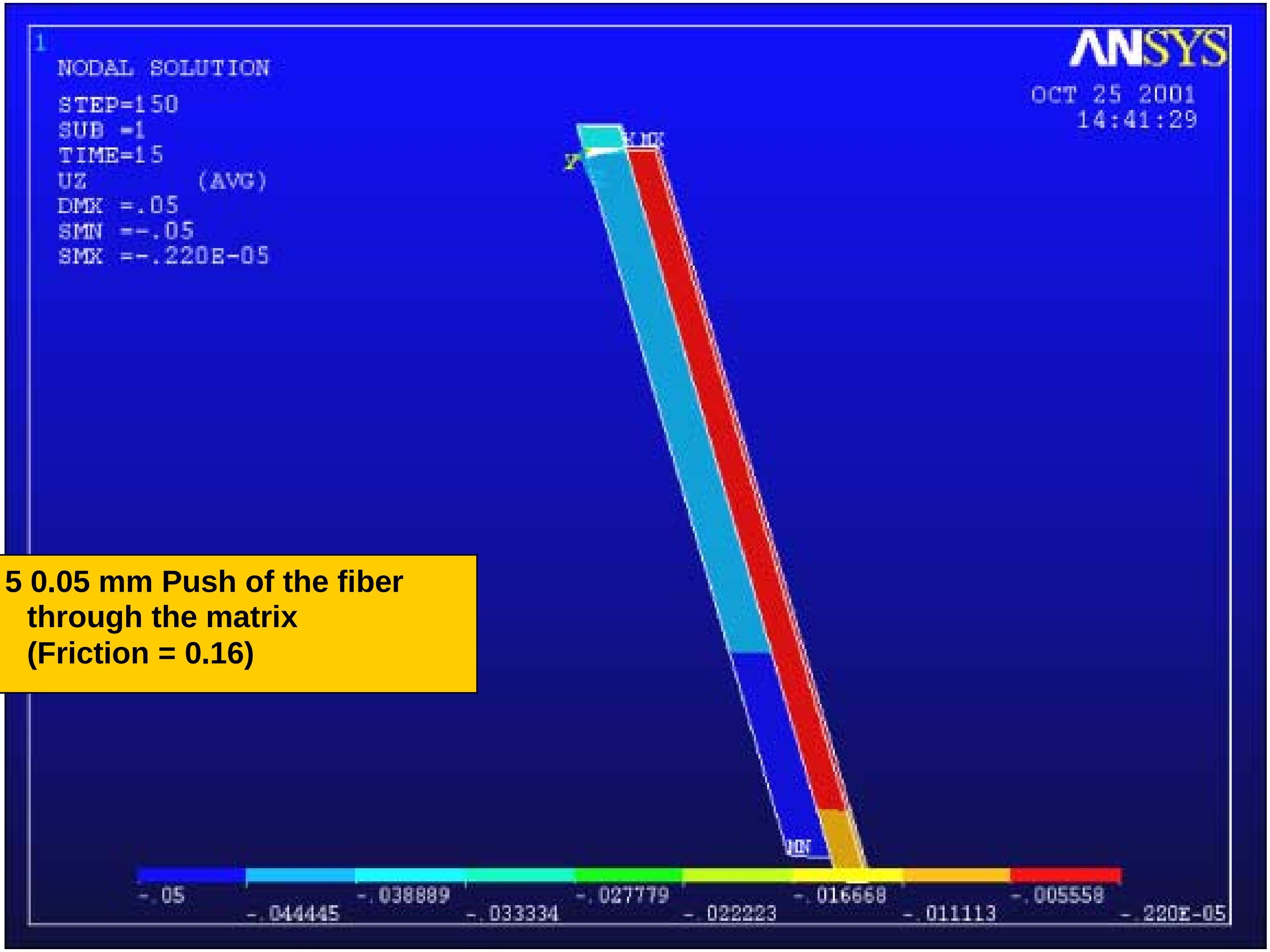


Fig. 5 0.05 mm Push of the fiber through the matrix (Friction = 0.16)

Fig. 6 Frictional Shear Stress on the contact elements (Friction = 0.16)

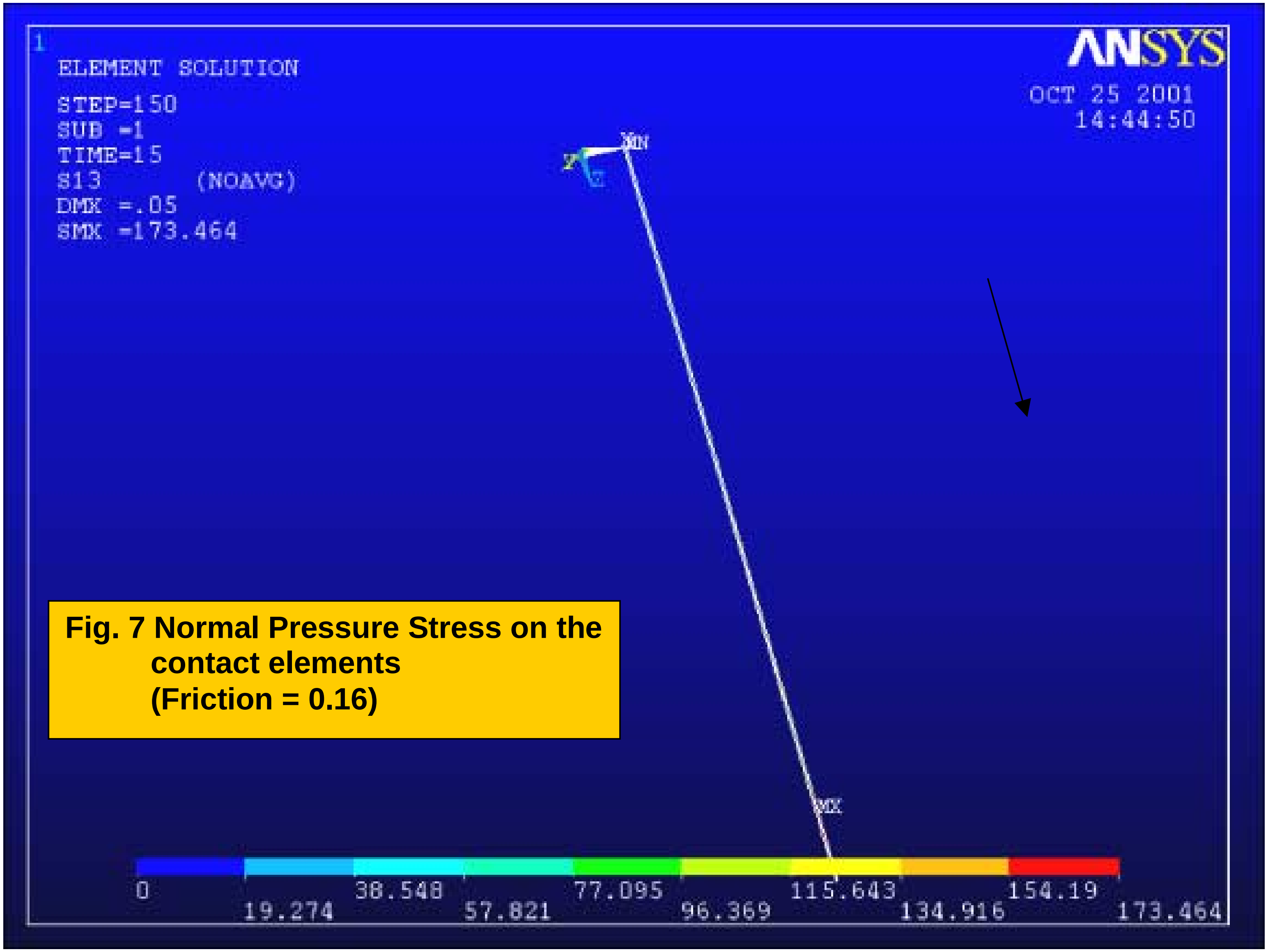


Fig. 7 Normal Pressure Stress on the contact elements (Friction = 0.16)

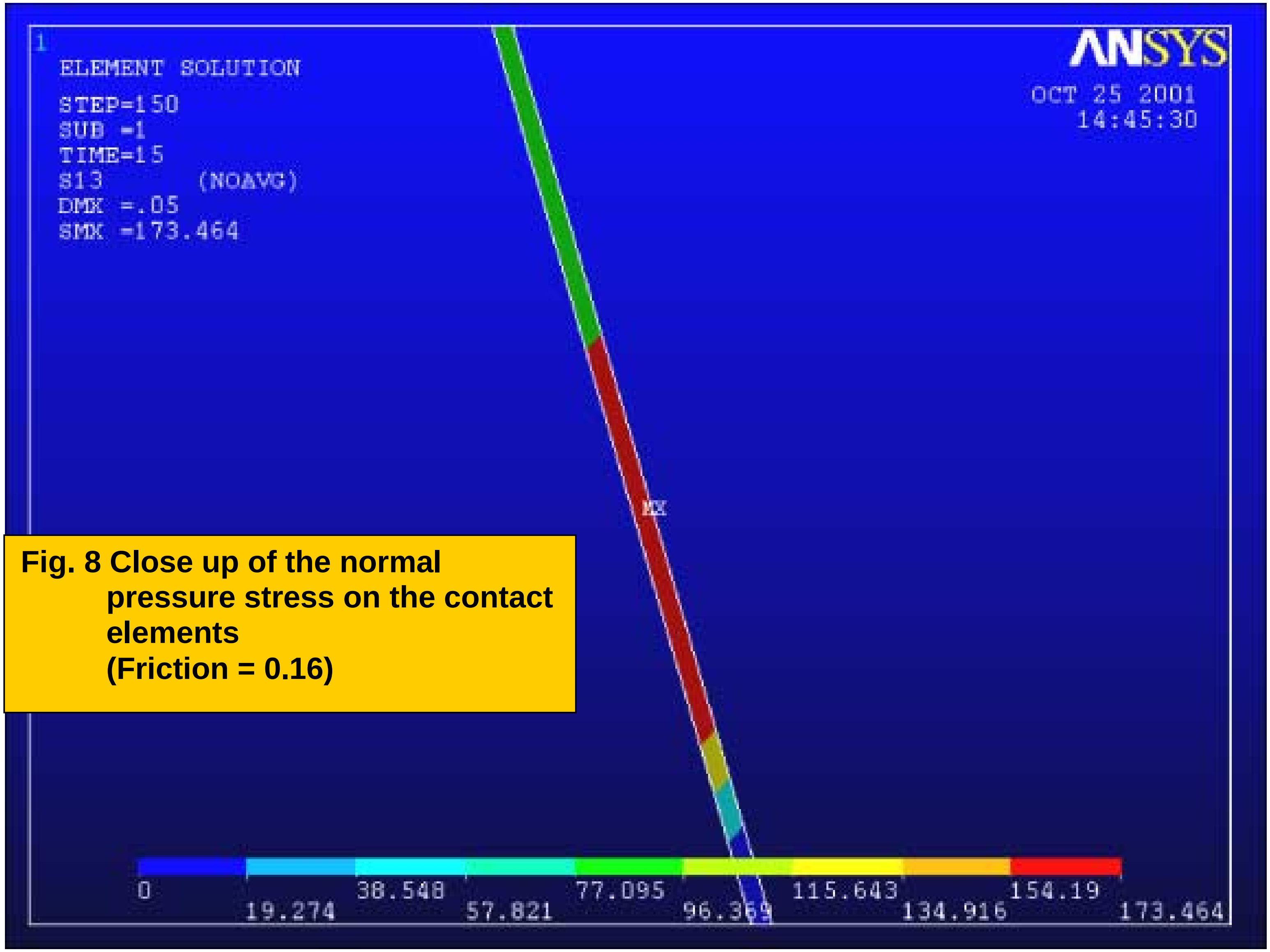


Fig. 8 Close up of the normal pressure stress on the contact elements (Friction = 0.16)