ANSYS: Potential Issues with Path Operations

Introduction

The issues considered in this technical note were picked up recently when considering a benchmark problem involving a bi-metallic strip. The axial stress distribution away from the ends of a bi-metallic strip subjected to a uniform temperature increase was derived by Timoshenko, [1] and is shown in Figure 1.

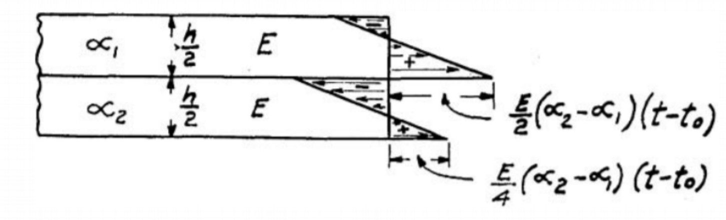


FIG. 3. *Distribution of normal stresses on any cross section of bi-metal strip while uniformly heated.*

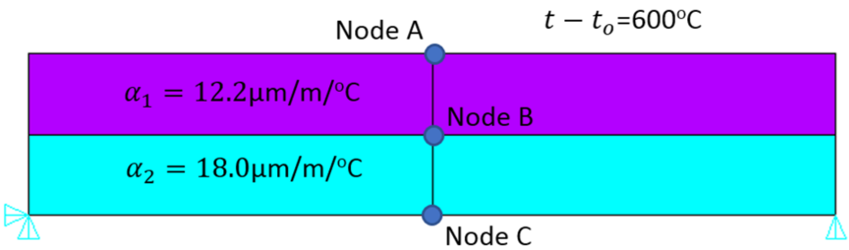
The elastic moduli for the strip are identical and equal to E and the strip has its temperature raised by $t - t_o$ where t_o is the temperature where no deformation of the strip occurs. The strips have identical thicknesses of $h/2$ and different coefficients of thermal expansion, α.

Figure 1: Axial stress distribution for a bi-metallic strip, [1]

This stress distribution is only valid away from the ends of the strip since, for equilibrium, the axial stresses must be zero at the free vertical edges. There is a boundary layer region towards the free edges where the axial stresses reduce to zero. This causes perturbations in the vertical direct stress and shear stress which are essentially zero in the interior of the strip and have maximum values towards or at the ends of the strip. The magnitudes of the axial stress at the interface between the two materials and at the outer faces are, according to Timoshenko, 365.4MPa and 182.7MPa respectively.

FE Model

The bi-metallic strip was analysed in ANSYS as shown in Figure 2.



The model uses eight-noded plane stress elements. These should be capable of modelling the expected linear stress distribution predicted by Timoshenko with reasonable accuracy although because of the end effects the values of the stress defining the distribution are not expected to agree exactly with the theoretical solution. This would, though, be expected to be achieved with mesh refinement. Three nodes are identified in the figure which will be used later to define a path in ANSYS.

Figure 2: Finite element model of a bi-metallic strip

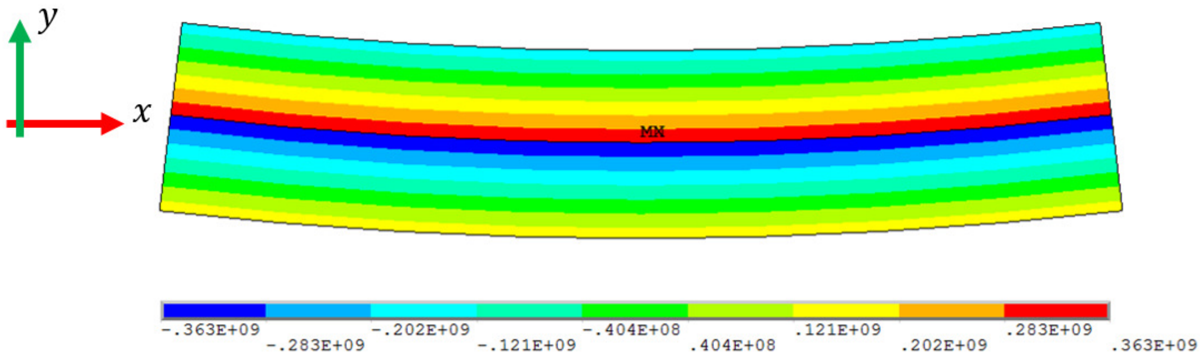
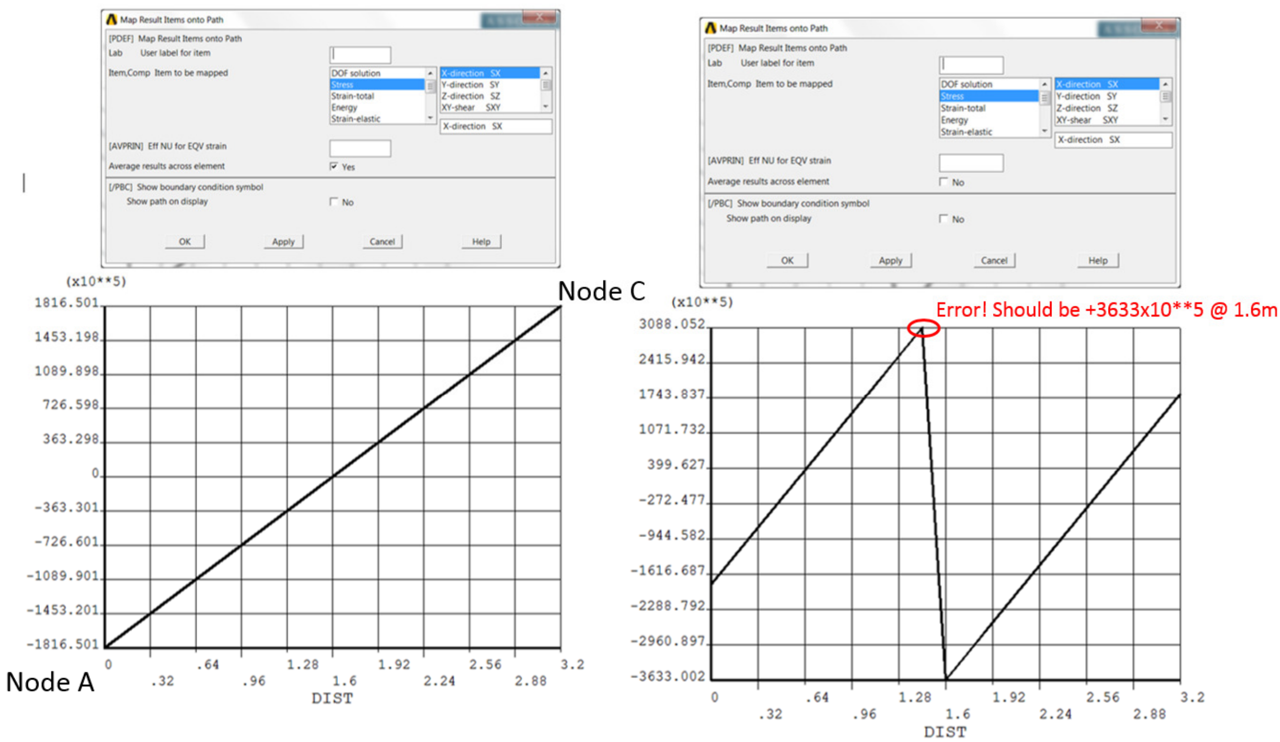


Figure 3: Contours of finite element direct stress in x direction (σ_x)

The magnitudes of the axial stress at the interface between the two materials and at the outer faces are, according to the finite element model, 363.30MPa and 181.65MPa respectively. As predicted, these values are very close to the values suggested by Timoshenko.

The path features within ANSYS were used to define a path between nodes A and C. The default settings were used. The stress component, σ_x, is, of course, discontinuous across the material interface and whilst the stress along this path may be plotted using nodal average values this would neglect the step change in stress seen at the material interface. The image on the left of Figure 4 shows the stress along the path using nodal averaged stresses and would appear to be correct albeit that stresses should not be averaged at material interfaces. The image on the right shows the stress along the path using unaveraged nodal stresses. There is an error in this plot as highlighted in red in the figure.



Nodal Averaged **Unaveraged**

Figure 4: Stress, σ_x, plotted along path Node A -> Node B -> Node C

Stress linearization is a procedure often used to post-process the FE stresses for use in certain codes of practice, e.g., the ASME Boiler & Pressure Vessel Codes. The membrane and membrane + bending distributions along the path for σ_x are shown in Figure 5.

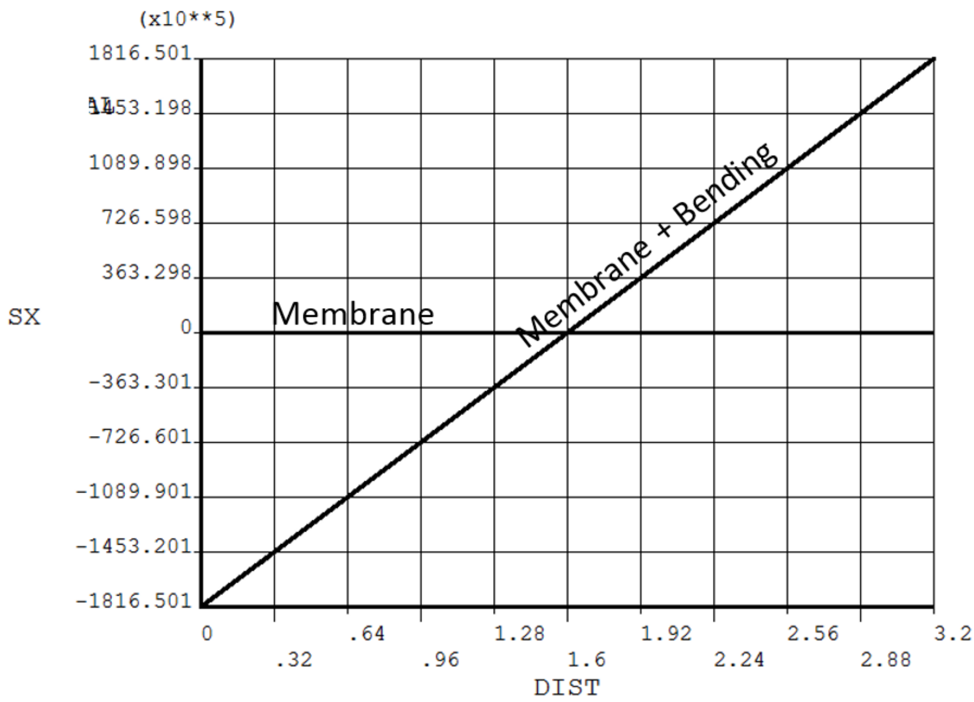


Figure 5: Linearised stress distribution

The linearised stress distributions show a significant resultant moment on the section defined by the path and this is clearly erroneous when compared with the theoretical distribution shown in Figure 1. The stress resultants on any section that cuts through the strip should, of course, be zero since there are no applied boundary or body forces. It seems that for linearization ANSYS uses the nodal averaged stresses. This is inappropriate for paths that go through a material discontinuity

Closure

This short technical note has illustrated two potential issues with the path operation features in ANSYS. The first issue seen is when plotting unaveraged stresses across a material interface with a step change in the stress. Although there should be two stress values at the discontinuity, one of these values is displaced from the interface and has an incorrect stress value. The second issue is with stress linearization across the material interface. It appears that ANSYS ignores the discontinuity and instead uses nodal averaged stresses at this point. This can introduce spurious stress resultants as seen in the example shown in this technical note.

References

[1] S. Timoshenko, 'Analysis of Bi-Metal Thermostats', Journal of the Optical Society of America, Vol. 11, Issue 3, pp. 233-255, (1925) https://doi.org/10.1364/JOSA.11.000233