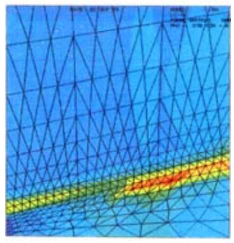
Modelling of Materials, Components & Processes

Continuum Damage Mechanics

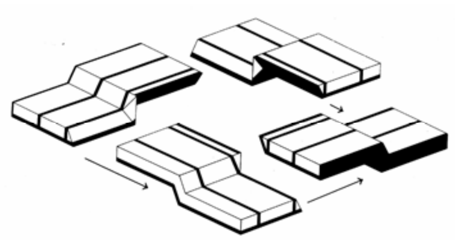


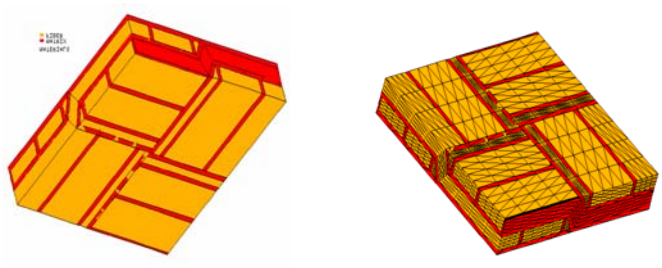
Professor D R Hayhurst
Dr M A Sheikh

- High-temperature CDM modelling.
- Finite Element Modelling of non-linear material and geometric response of high-temperature components.
- Lifing and remnant life assessment of butt welds and of transition welded joints at high temperatures in 2- and 3-D.

Damage and Thermal Transport in Composites

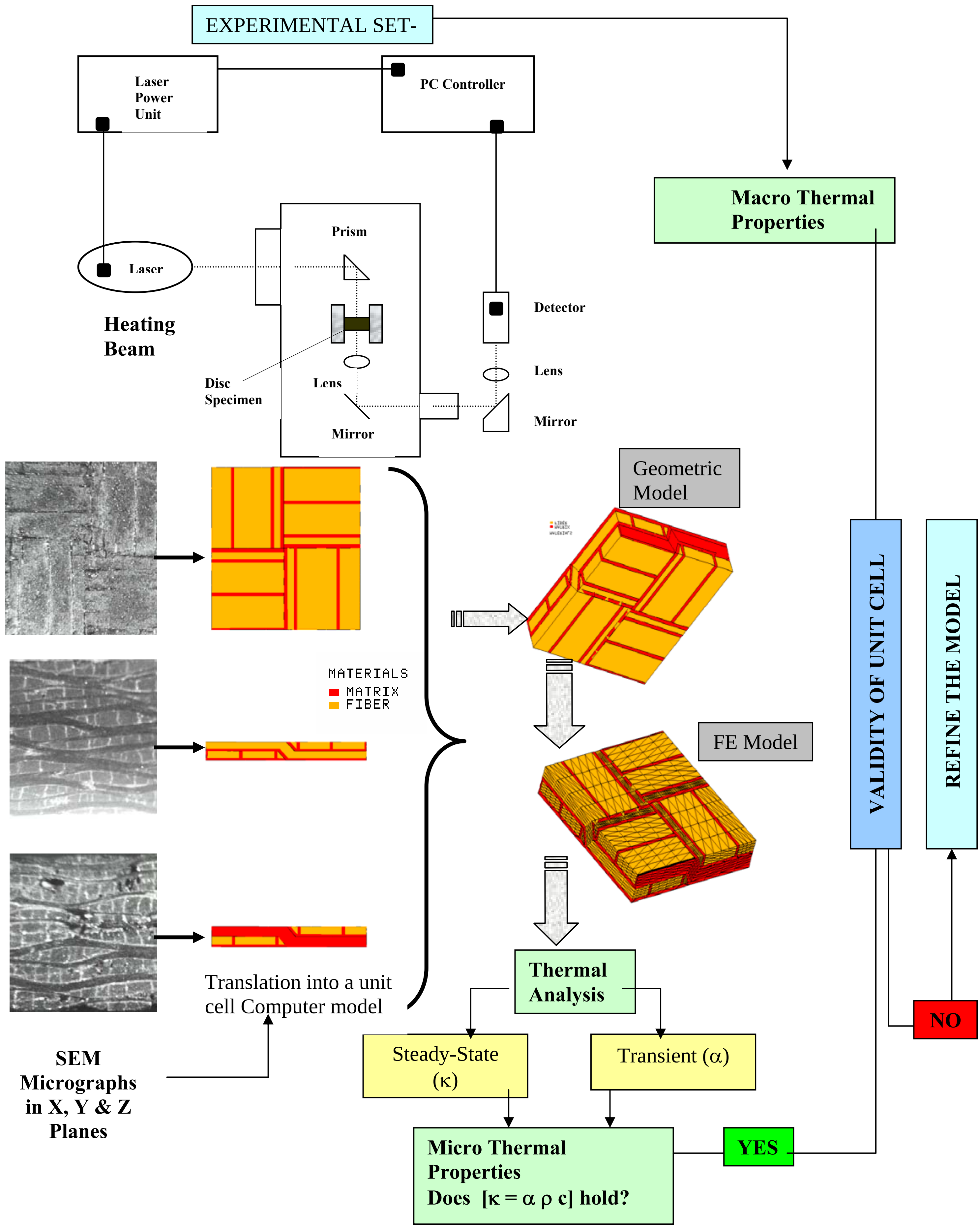
Professor D R Hayhurst
Dr M A Sheikh





Finite Element Model of a unit cell of a woven composite for thermal and mechanical analysis

- Component design with Ceramic Matrix Composites (CMCs).
- Prediction of Thermal Transport in Composites.
- Use of thermal transport properties to quantify damage in CMC components.


EXPERIMENTAL SET-
Laser Power Unit
PC Controller
Macro Thermal Properties
Prism
Laser
Heating Beam
Detector
Lens
Disc Specimen
Lens
Mirror
Mirror
Geometric Model
MATERIALS
MATRIX
FIBER
FE Model
VALIDITY OF UNIT CELL
REFINE THE MODEL
Thermal Analysis
Translation into a unit cell Computer model
SEM Micrographs in X, Y & Z Planes
Steady-State (κ)
Transient (α)
NO
YES
Micro Thermal Properties
Does [κ = α ρ c] hold?

<u>**Publications**</u>

M. A. Sheikh, S. Taylor, D. R. Hayhurst and R. Taylor, "*Measurement of Thermal Diffusivity of Isotropic Materials using the Laser Flash Method and its validation by Finite Element Analysis"*, J. Phys. D: App. Phys. **33**, 2000, pp. 1536-1550.

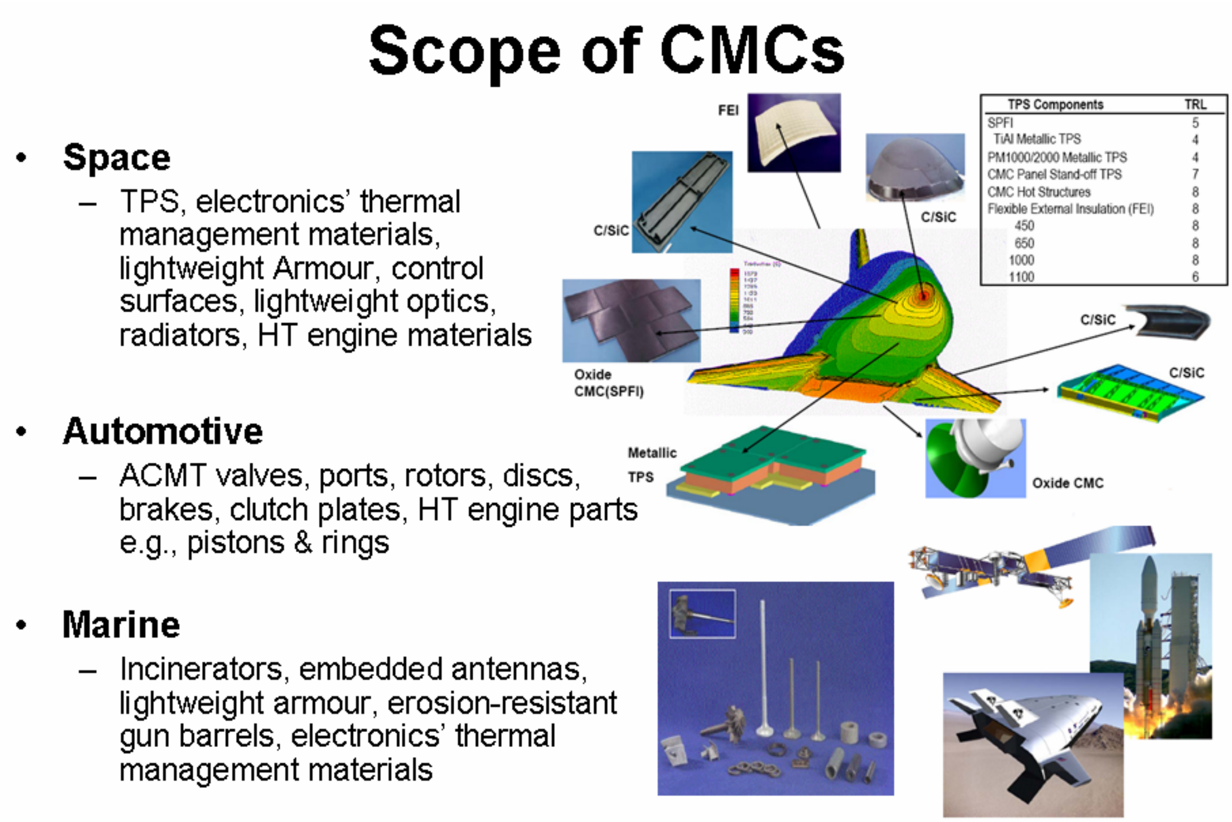
M. A. Sheikh, S. Taylor, D. R. Hayhurst and R. Taylor, "*Microstructural Finite Element Modelling of a Ceramic Matrix Composite to predict Experimental Measurements of its Macro Thermal Properties*", Modelling Simul. Mater. Sci. Eng. **9**, 2001, pp. 7-23.

M. A Sheikh, "*Finite Element Modelling for the determination of Thermal Transport Properties of High Temperature Composites*", Collected Articles of the Society of Construction & Architecture, 2001 – 1(**26**), pp. 137-148.

Paolo Del Puglia, **Mohammed A Sheikh** and David R Hayhurst, "*Classification and Quantification of Initial Porosity in a CMC Laminate*", Composites Part A: Applied Science and Manufacturing, **35**, 223-230, 2004.

P Del Puglia, **M A Sheikh** and D R Hayhurst, *Modelling the degradation of thermal transport in a CMC material due to three different classes of porosity*, J. of Modelling Simul. Mater. Sci. Eng., Vol. **12**, 2, 2004.

P Del Puglia, **M A Sheikh** and D R Hayhurst, *Thermal Transport Property Prediction of a CMC Laminate from Base Material Properties and Manufacturing Porosities*, Proc. R. Soc. A, **461**, 3575-3597, 2005.

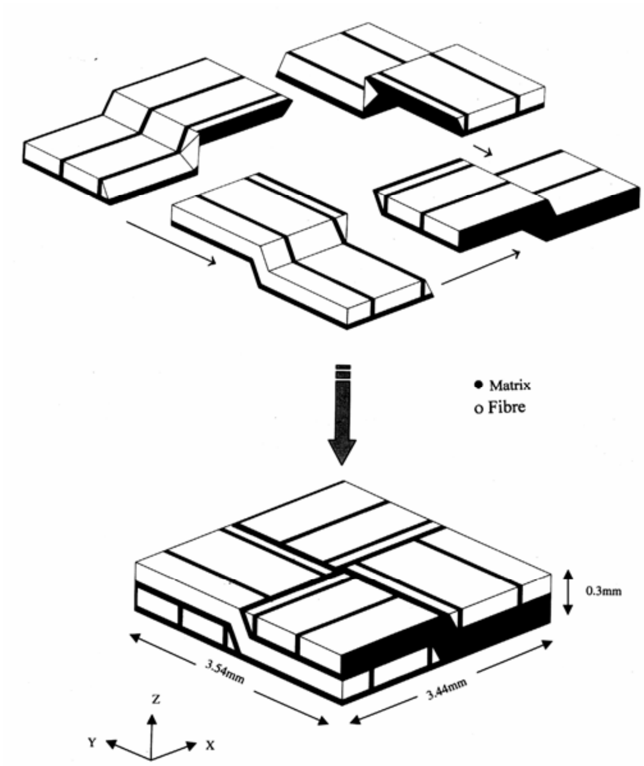


Modelling of Composites

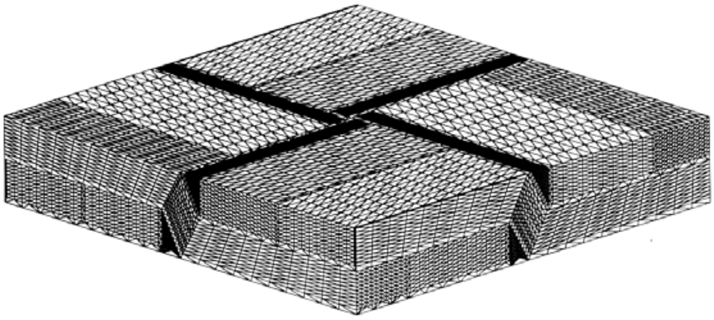
Dr M A Sheikh

Dr P Mummery (Materials Science)

Dr P Potluri (Textiles)



Refined Mesh for the Unit Cell Model of DLR-XT with 25, 178 Nodes & 124, 114 Tetrahedral Elements



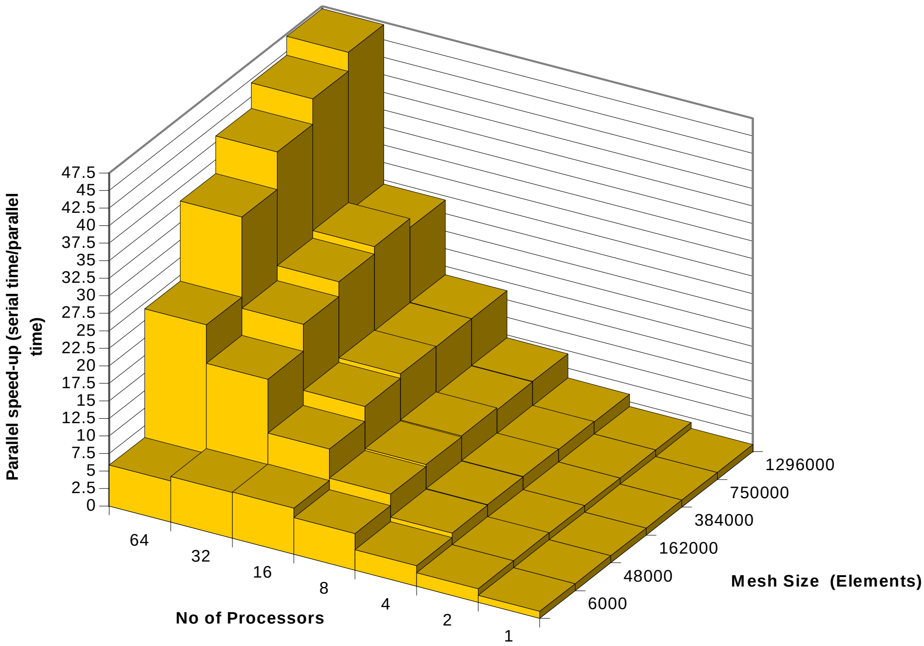
Publications

Johar Farooqi and **M A Sheikh**, *Finite Element Modelling of Thermal Transport in Ceramic Matrix Composites*, Accepted for publication in International Journal of Computational Materials Science, 2006.

Parallel Processing

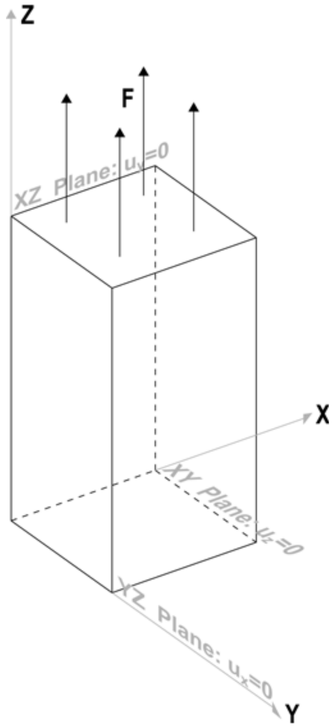
Dr M A Sheikh
Dr Lee Margetts (Manchester Computing)

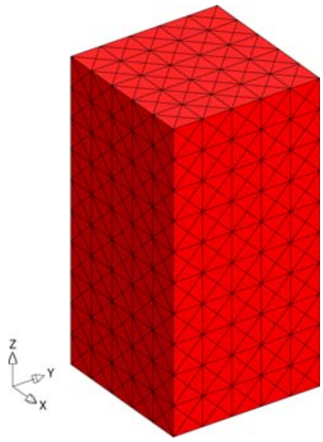
Research into use of parallel iterative solvers in a multi-processor environment for 3-D finite element analysis of engineering structures



Iterative solver parallel speed-up (serial execution time over parallel execution time) against number of processors and mesh size (elements) for an iterative tolerance of 1×10^{-5}

Bar model: loading and the planes of restraints.





A sample mesh of the modelled bar with 6000 elements

<u>Publications:</u>

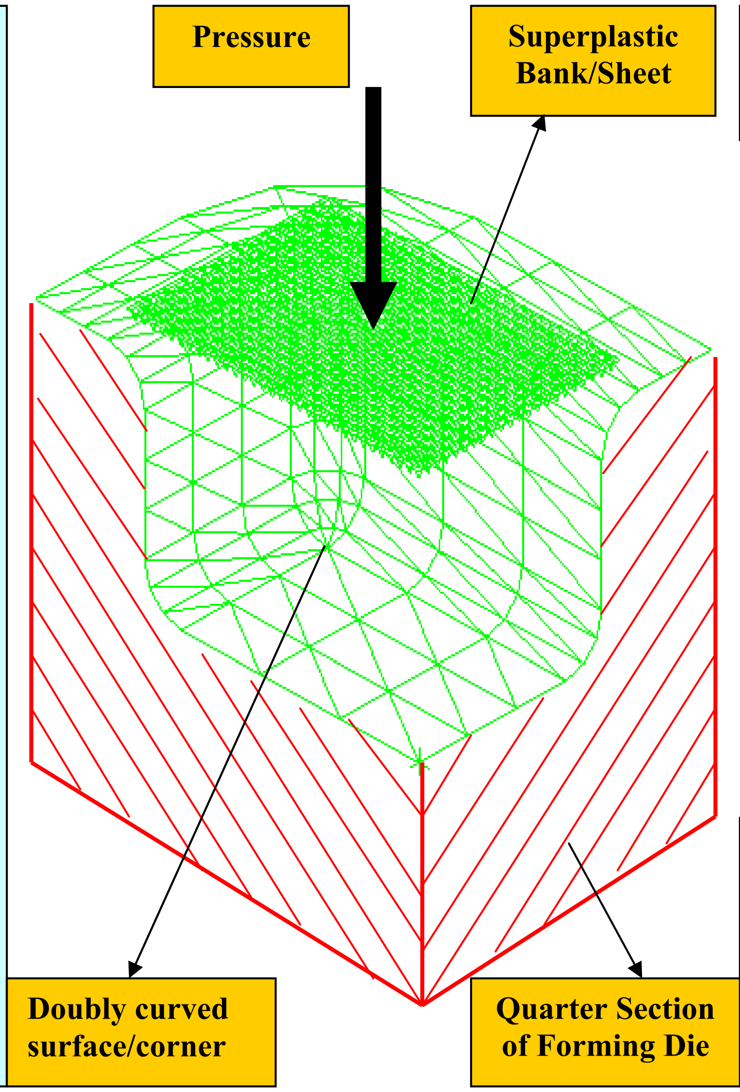
J. R. Hayhurst, **M. A. Sheikh** and L. Margetts, *On the Use of a Parallel Preconditioned Conjugate Gradient Solver for 3-D Finite Element Creep Analysis*, Submitted for publication in Computer Methods in Applied Mechanics and Engineering, 2006.

Modelling and Simulation of Manufacturing Processes

Finite Element Simulation of Superplastic Forming of Doubly Curved Surfaces/Corners

Dr M A Sheikh

The superplastic forming process consists of clamping a sheet against a die whose surface forms a cavity of the shape required. Gas pressure is then applied to the opposite surface of the sheet, forcing it to acquire the die shape. The example considered here is the superplastic forming of a rectangular box.



Blank Material

Superplastic Aluminum Alloy

[Al-6Cu-0.4Zr]

Young' Modulus

E = 71GPa

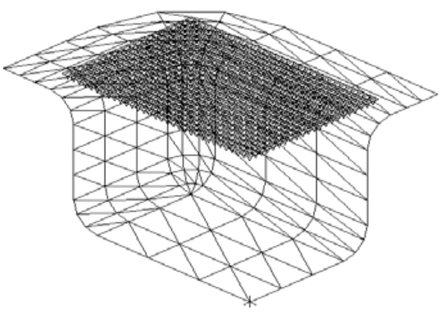
Poisson's Ratio

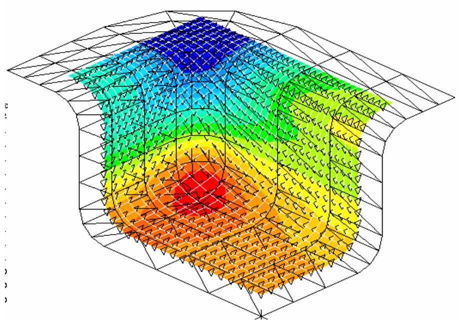
ν = 0.34

Flow Stress Rule

$$\sigma^f = A\,(\dot{\varepsilon}^{pl})^{½}$$

A = 179.2 MPa





Superplastic metals exhibit high ductility and very low resistance to deformation and are, thus, suitable for forming processes that require very large deformations.

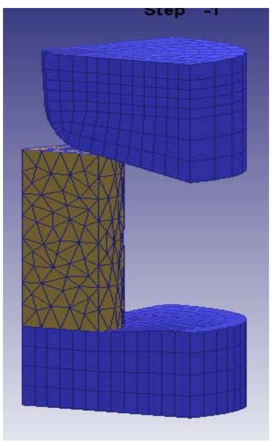
Superplastic Forming has a number of advantages over conventional forming methods:

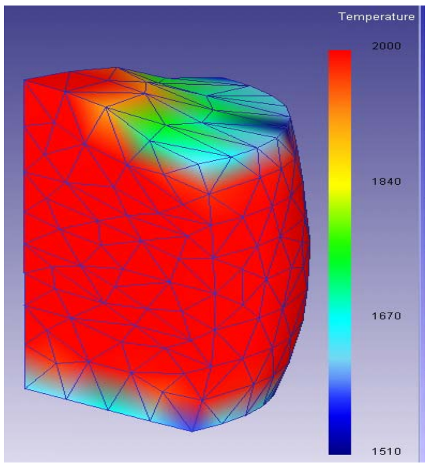
- **Forming is accomplished in one step rather than several, and intermediate annealing steps are usually unnecessary.**
- **This process allows the production of relatively complex, deep-shaped parts with quite uniform thickness.**
- **Tooling costs are lower since only a single die is usually required.**

Drawbacks associated with this method include the need for tight control of temperature and deformation rate. Very long forming times make this method impractical for high volume production of parts. Computer simulations assist in designing the process by giving an insight into the controlling parameters.

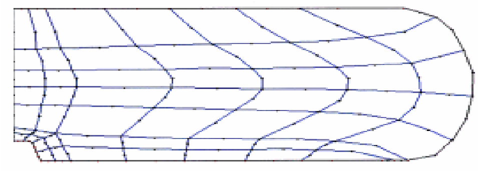
Superplastic forming operations are used to create complex three-dimensional shapes in sheet material for use in aeroengine applications. Typical components are wing and fuselage skins, radomes and pressure containers. In all cases minimum weight is a prime consideration.

Finite Element Analysis of a non-isothermal spike forging – Temperature distribution

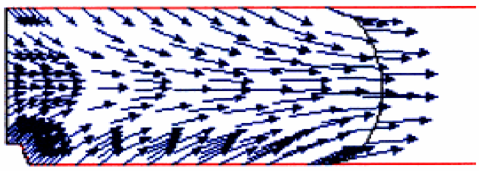




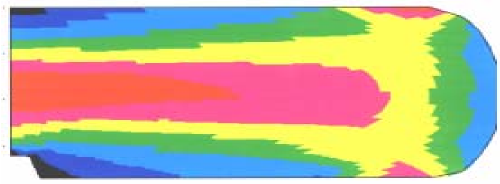
Forging Simulation of a Compressor Disc



FE Model – Deformed mesh



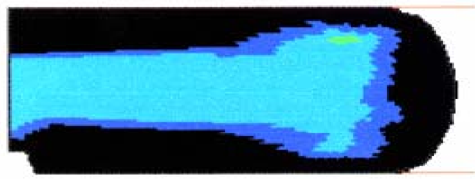
Nodal velocities



Effective Strain

Effective Stress Distribution

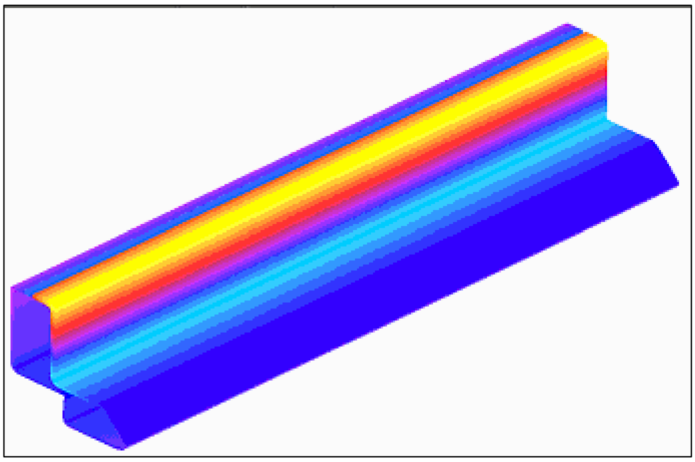
Temperature Distribution [1149 – 1300 C]

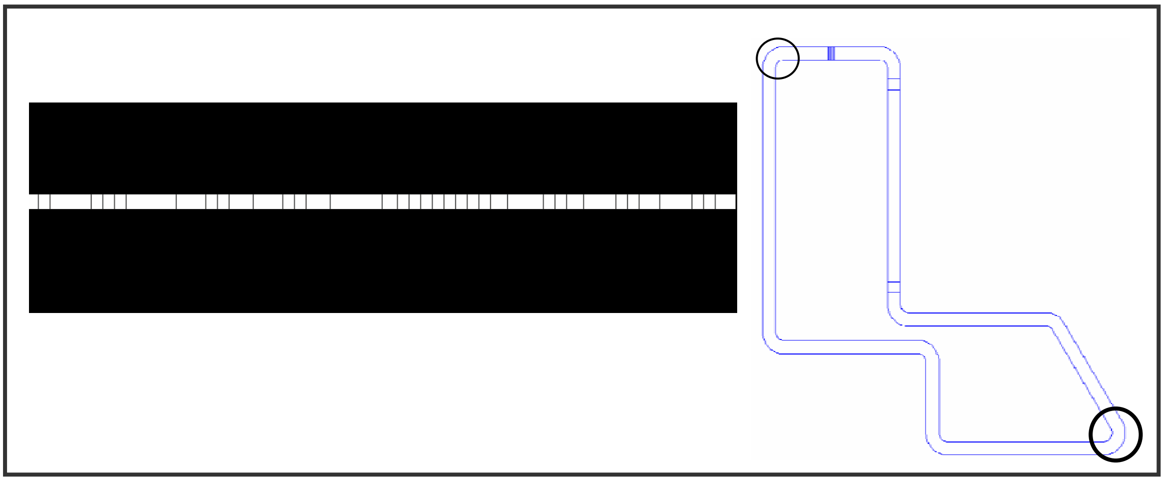


Maximum grain size [ASTM Scale: 1 – 13]

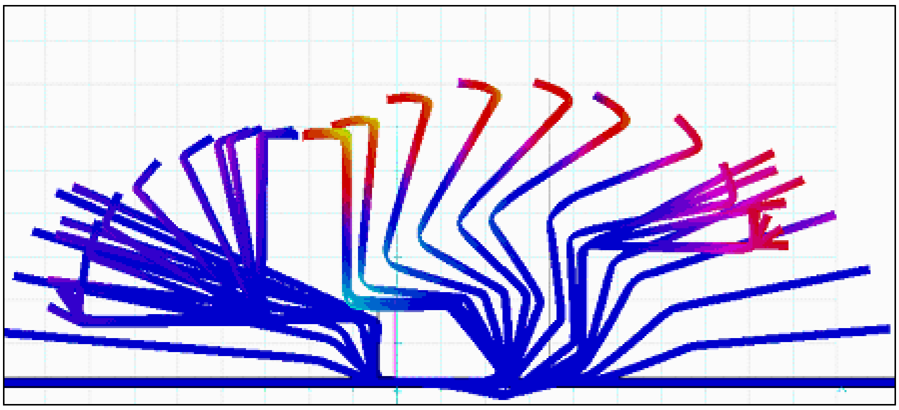
Average grain size

FINITE ELEMENT ANALYSIS OF THE ROLL FORMING PROCESS

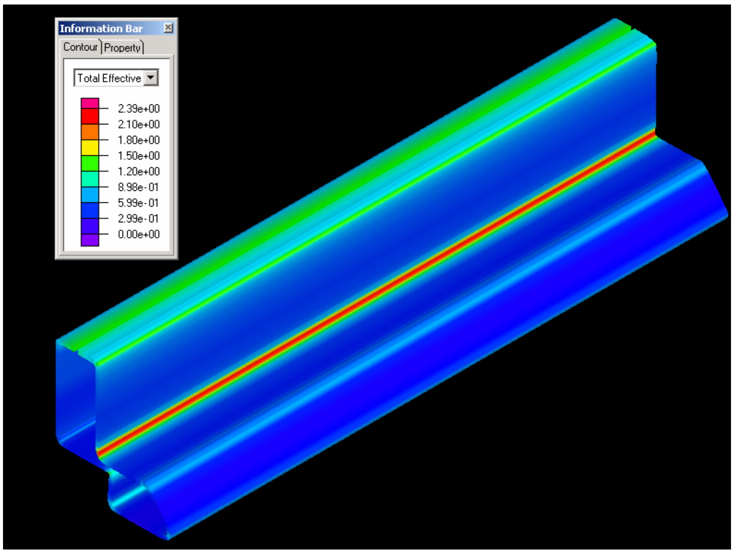




Initial Mesh corresponding to the Final Section



Flower Pattern (Pass1 –Pass 26 Sections)



Effective Strain Rate on the Final Section

Publications

M. A. Sheikh and R. R. Palavilayil, *An Assessment of Finite Element Software for Application to Roll Forming Process*, Accepted for publication in Journal of Materials Processing Technology, 2006.

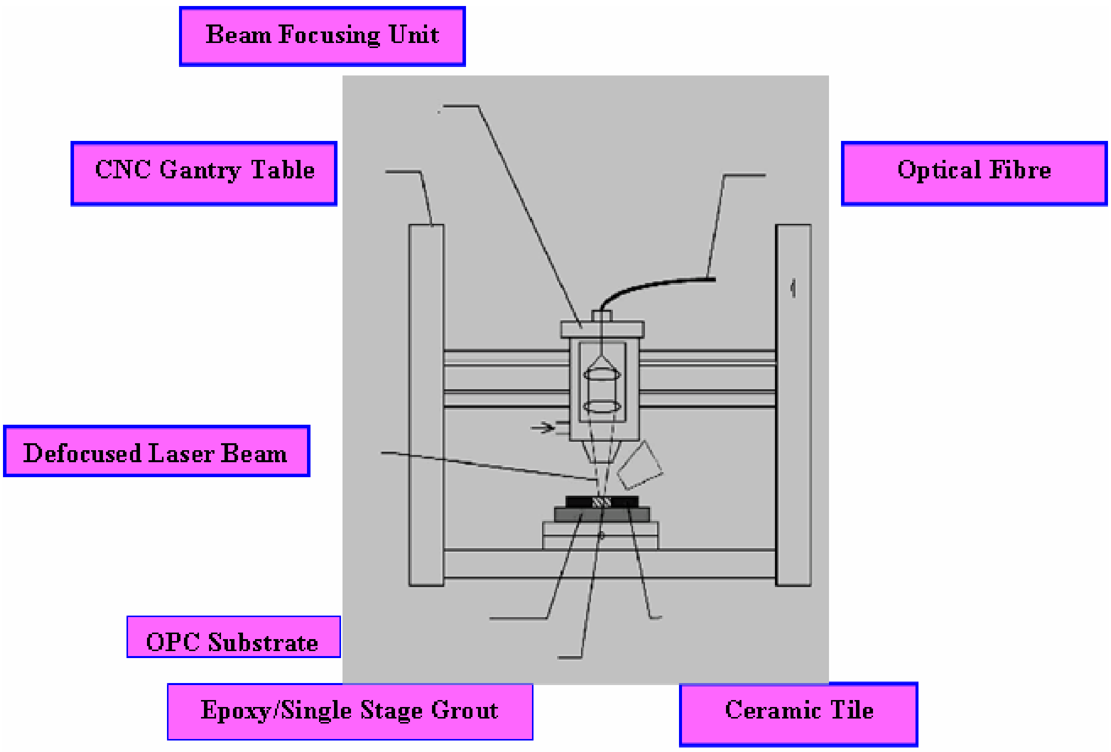
M. A. Sheikh, *An Assessment of Recent Developments in the Finite Element Software for Modelling Manufacturing Processes*, Accepted for publication in the International Journal of Manufacturing Technology and Management, 2006.

Modelling of Laser Material Processing

Finite Element Modelling of laser tile grout sealing process

Dr M A Sheikh
Professor Lin Li

Ceramic tiles are one of the most cleanable surfaces available. A major difficulty with tiled surfaces is that contaminants (e.g. biological, chemical and nuclear) can pass around the edges and through the porous grout, causing it to become contaminated over time. A novel technique has been developed which allows ordinary ceramic tiles to be successfully sealed using a 60W Laser. The process consists of using a crushed ceramic tile mix and a commercially available vitreous enamel to seal the void between the adjoining tiles. The process has been modelled using the Finite Element Method to study the thermo-mechanical behaviour of the materials.



Experimental Set-up

Heat Transfer Equations

Energy Balance:

$$\int_V \rho \dot{u} dV = \int_S q dS + \int_V Q dV$$

Constitutive Definition

Specific heat effect:

$$C(T) = \frac{dU}{dT}$$

Latent heat effect:

$$Q_f = -\rho L \frac{dV}{dt}$$

Governing Heat Conduction Equation:

$$f = -k \frac{dT}{dX} \qquad k = k(T)$$

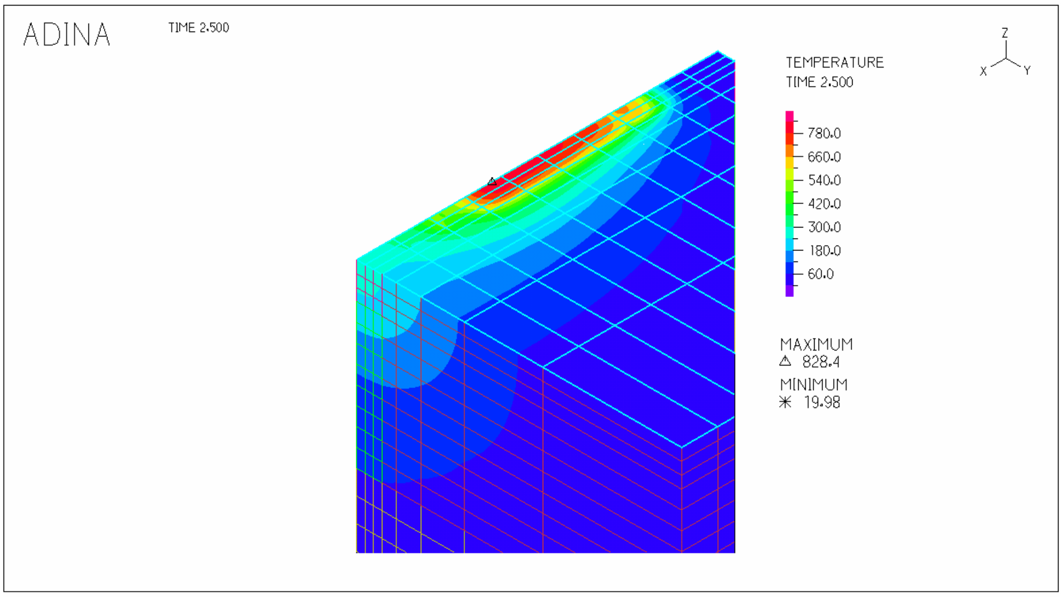
Boundary conditions:

Temperature: $T = T(X, t)$

Heat Flux: $q = q(X, t)$

Convection: $q = h(T - T_0)$

Radiation: $q = \varepsilon \sigma (T^4 - T_0^4)$



Thermal distribution after 2.5 seconds (Laser Power 60W: Speed 3mm/sec)

<u>Publications</u>

A. Nisar, M. J. J. Schmidt, **M. A. Sheikh** and L. Li, Three-Dimensional Transient *Finite Element Analysis of Laser Enamelling Process with Moving Heat Source and Phase Change Considerations*, IMechE Proceedings: Journal of Engineering Manufacture - Part B, **217**, 753-764, 2003.

A. Nisar, M. J. J. Schmidt, **M. A. Sheikh** and L. Li, *Finite Element Analysis for the prediction and optimisation of residual stresses caused by laser enamelling*", IMechE Proceedings: Journal of Engineering Manufacture - Part B, **217**, 1085-1099, 2003.

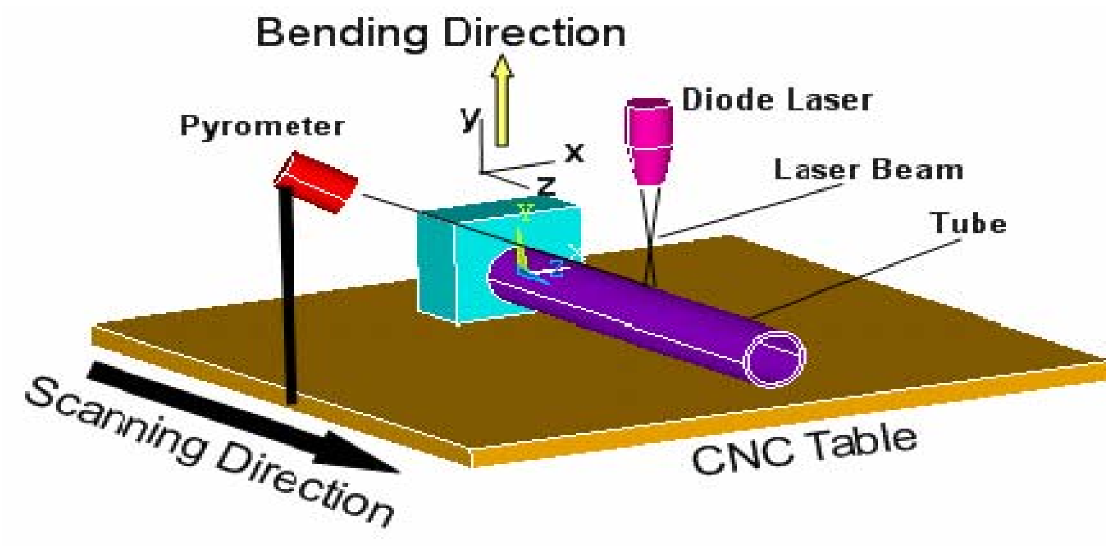
Amer Liaqat, Shakeel Safdar and **M A Sheikh**, *Finite Element Modelling of a Moving Laser Beam for Thermo-Mechanical Analysis of a Ceramic Tile Grout Sealing Process*, Accepted for publication in IMechE Proceedings: Journal of Mechanical Engineering Science - Part C, 2006.

Modelling the Effects of Laser Beam Geometry on Laser Surface Processing of Materials

Laser material processing over the years has developed into a major industrial tool. The way the temperature is distributed inside the material is of prime importance in any thermal process. Based on the temperature distribution and its transient behaviour one can determine the heating/cooling rat

The Process

A possible method of varying the temperature distribution hence the heating /cooling rate and thermal gradient (without changing input power or scanning speed) is by modifying the geometry of laser beams. Majority of laser material processing is carried out either with circular or rectangular beam geometry. A variation in beam geometry may offer advantage by altering the temperature distribution thereby varying the cooling rates and thermal stresses. The beam geometry can be varied by the use of various optical

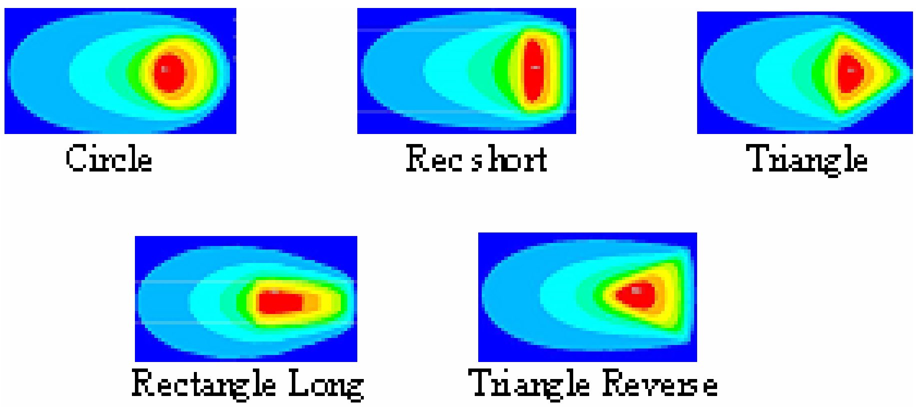


Schematic representation of (tube bending)

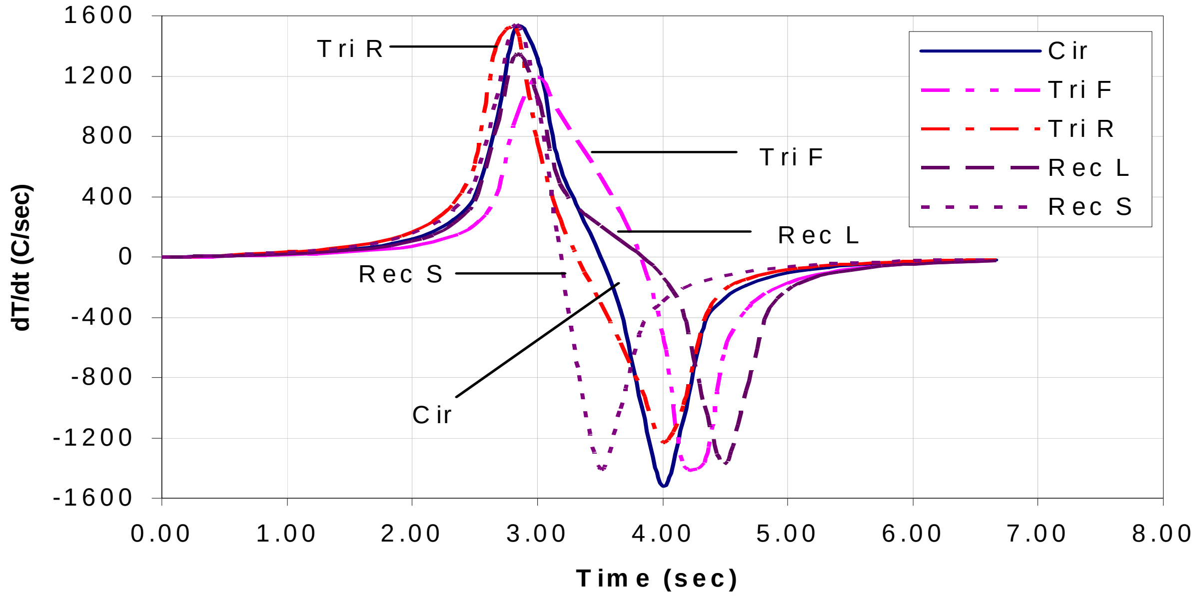
Modelling the effects of laser beam geometries in laser material processing is a demanding task. A finite element model has been constructed to analyse the effect of various laser beam shapes on laser processing.

$$[C]\{\check{T}\} + [K]\{T\}=\{Q\ (t)\}$$
$$[M(T)]\{\ddot{u}(t)\}+[C(T)]\{\mathring{u}(t)\}+[K(T)]\{u(t)\}=\{F(t)\}+\{Fth\ (t)\}$$

A commercial finite element package, ANSYS, has been used to simulate the process. Experimental validation of some of the results has also been carried out. The model has been utilised to investigate the effect of beam geometry on laser transformation hardening and laser tube bending.



Isotherms on the top surface as predicted by the model

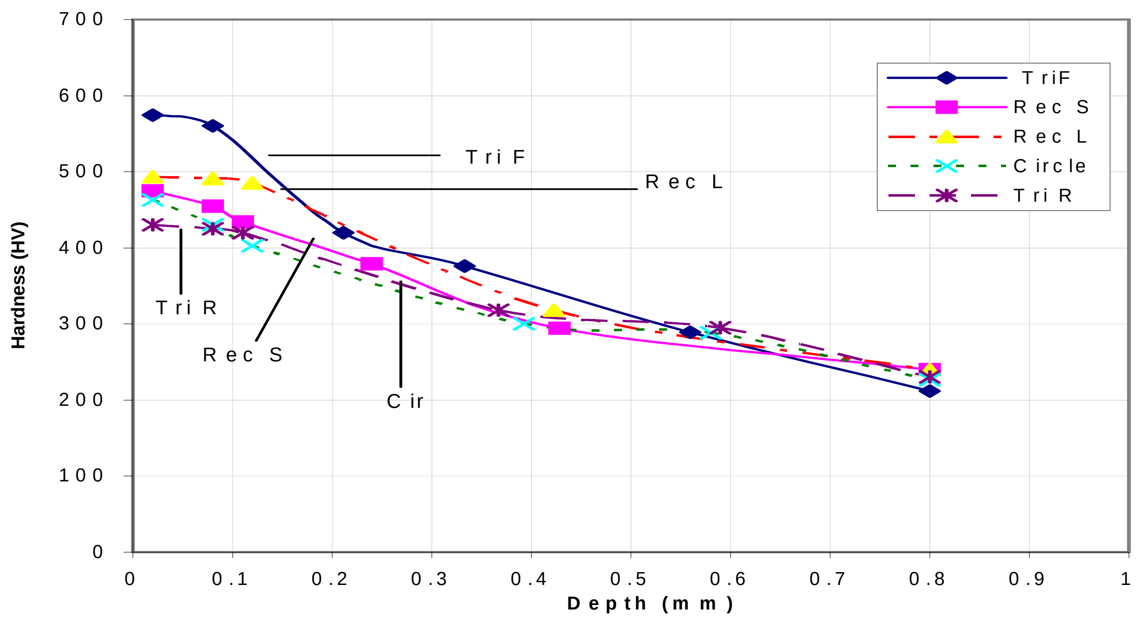


Heating and cooling rates for different beam geometries as predicted by model

Results

Laser Transformation Hardening

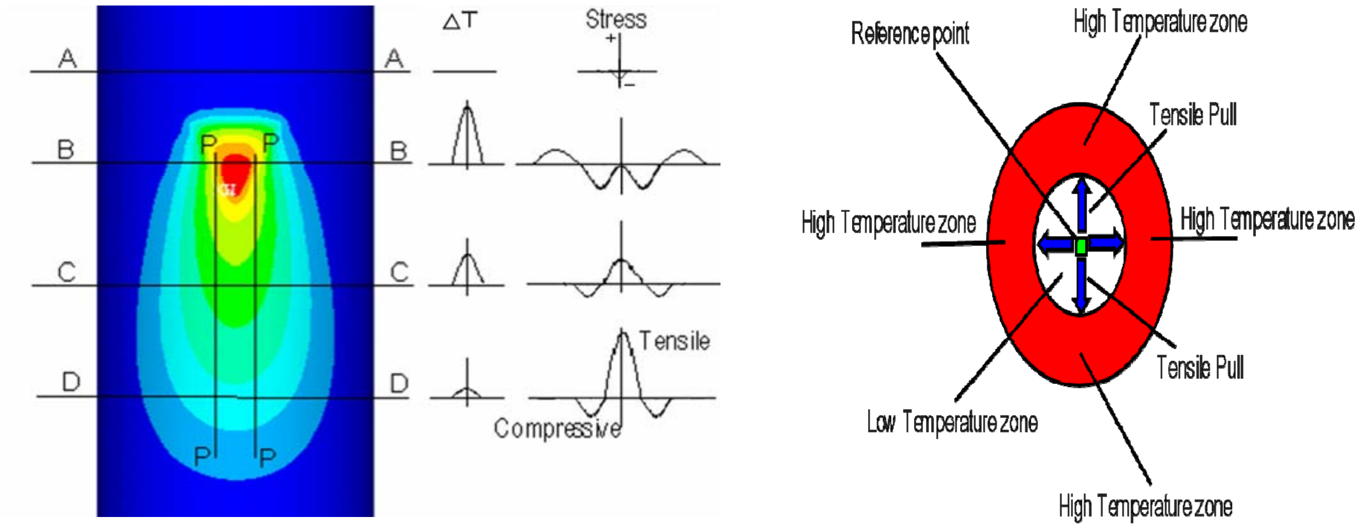
Triangular beam has been found to give better homogenisation and hardness as compared to circular and rectangular beams owing to its lower heating rate.



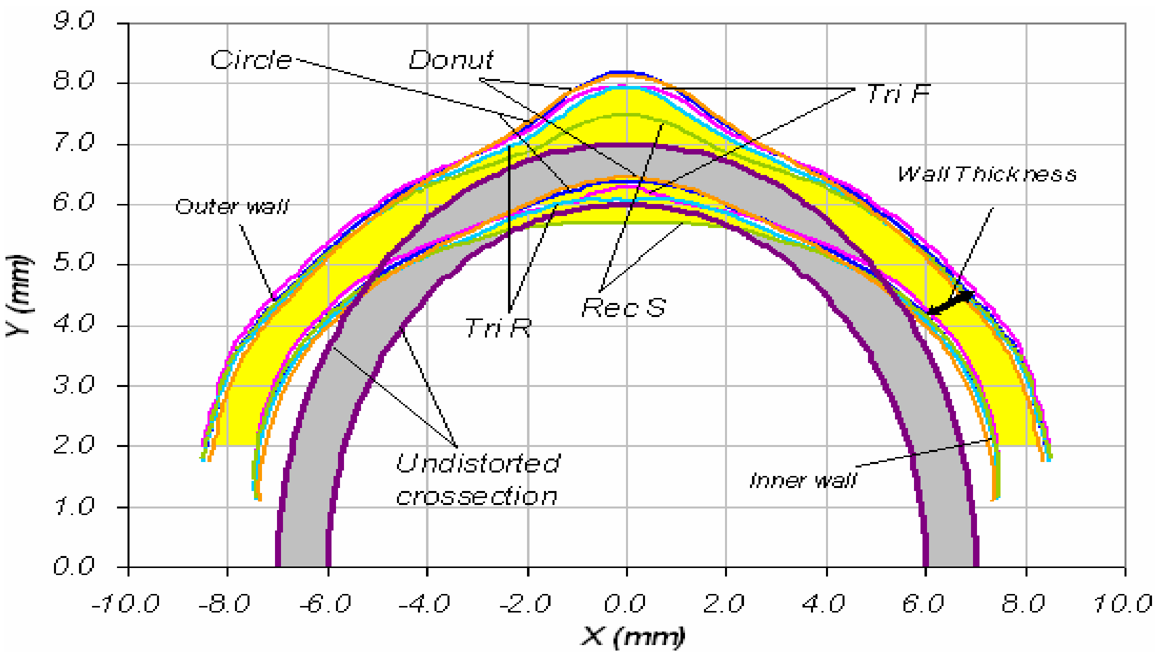
Experimentally measured hardness (HV) vs depth for different beam geometry

Laser Tube Bending

Thermal stresses generated during laser scanning are strongly dependent upon laser beam geometry. Non-conventional beams like Tri-R and Donut beam seem to provide better results with regard to distortion and bending angle mainly due to their unique stress states. Donut beam has the least lateral distortion due to its peculiar transient bi-axial stress state. Though the conventionally used circular beam provides higher bending angle but the distortions associated with circular beam are much higher as compared to non-conventional beams.



Transient stress states for a solid and a donut beam
Note the peculiar bi-axial stress state for a donut beam



Cross-sectional profile of tube for different beam shapes after laser tube bending (distortions increased by 100 times to highlight differences)

Conclusions

Based on the results mentioned above it is evident that the beam geometry provides us with a useful tool to manipulate temperature distribution in order to optimise laser material processing. The applications of laser beam geometry as an optimisation tool are only limited by visualisation.

Publications

Shakeel Safdar, Lin Li, **M. A. Sheikh** and Zhu Liu, *An Analysis of the Effect of Laser Beam Geometry on Laser Transformation Hardening*, Accepted for publication in ASME Journal of Manufacturing Science & Eng, 2006.

Shakeel Safdar, Lin Li, **M. A. Sheikh** and M. J. Schmidt, *A Thermal History Analysis of Surface Heating of Mild Steel with Different Laser Beam Geometries*, Accepted for publication in IMechE Proceedings: Journal of Mechanical Engineering Science - Part C, 2005.

Shakeel Safdar, Lin Li, **M A Sheikh** and Zhou Liu, *The Effect of Non-Conventional Laser Beam Geometries on Stress Distribution and Distortions in Laser Bending of Tubes*, Submitted for publication in ASME Journal of Manufacturing Science & Eng, 2006.

Shakeel Safdar, Lin Li, **M A Sheikh** and Zhou Liu, *Finite Element Simulation of Laser Tube Bending: Effect of Scanning Schemes on Bending Angle, Distortions and Stress Distribution*, Submitted for publication in Optics & Laser Technology, 2006.

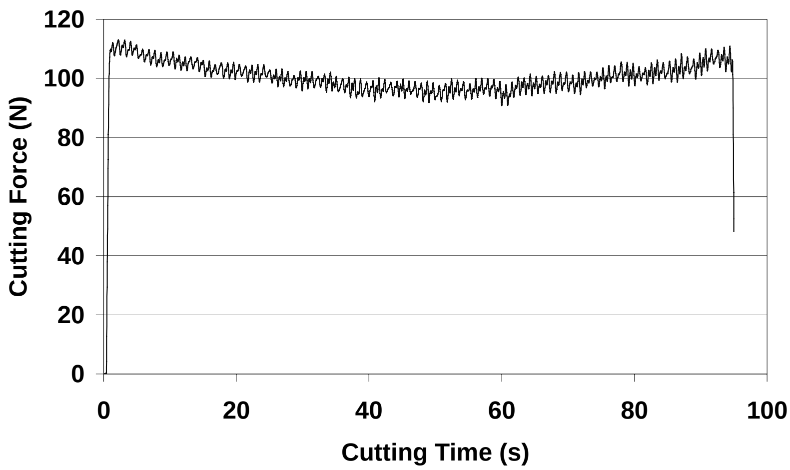
Modelling and Simulation of High Speed Machining Processes

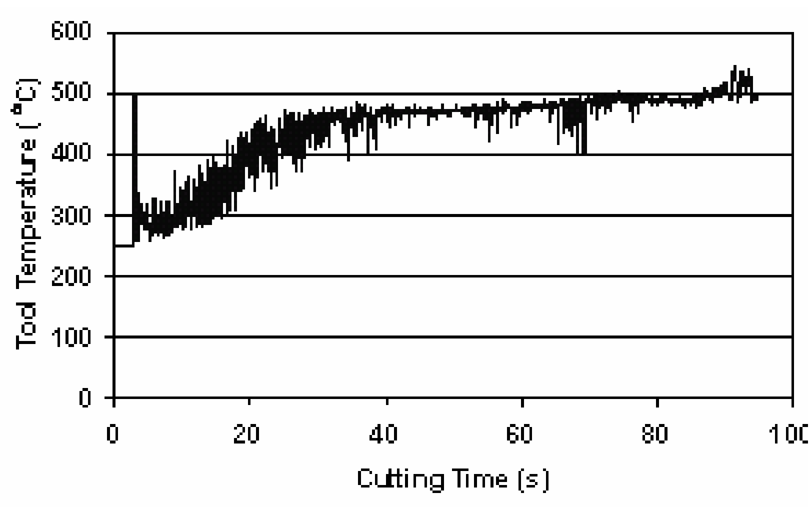
Dr M A Sheikh
Dr P Mativenga

FE Thermal Analysis for Heat Partition and Tool Wear in Hard Turning of Tool Steel

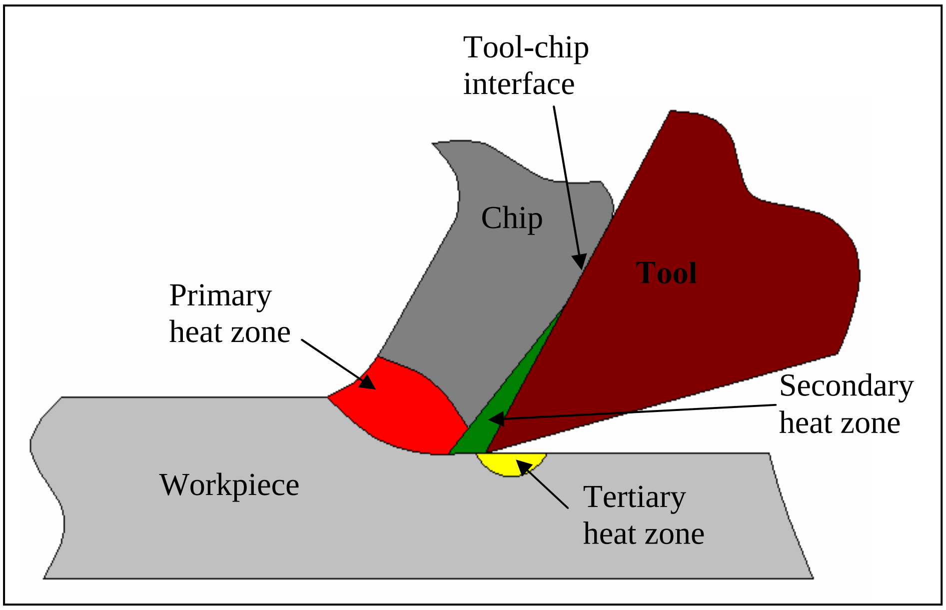
Method:

The approach followed here required both experimental work and Finite Element thermal Modelling. The experiments involved measuring the cutting forces, cutting temperatures, tool wear, and the contact area.



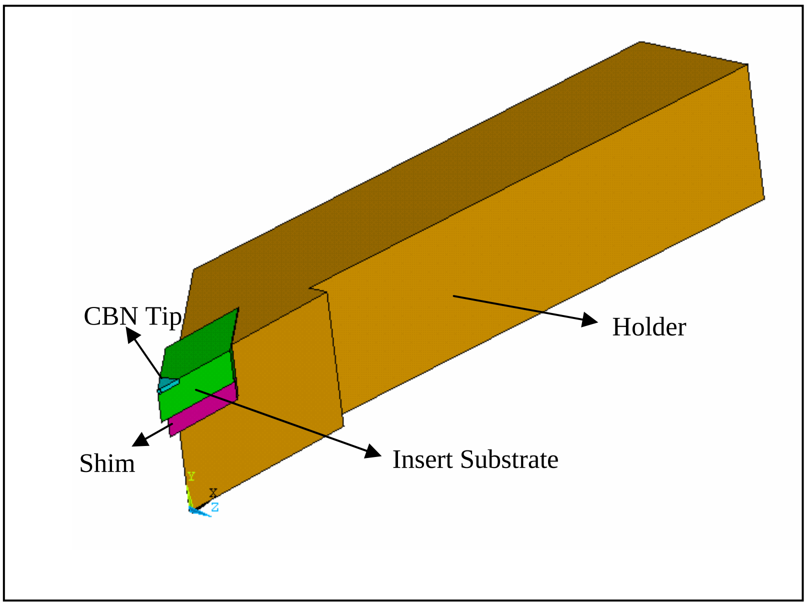


Using the measured cutting forces and the contact area in the orthogonal cutting model,

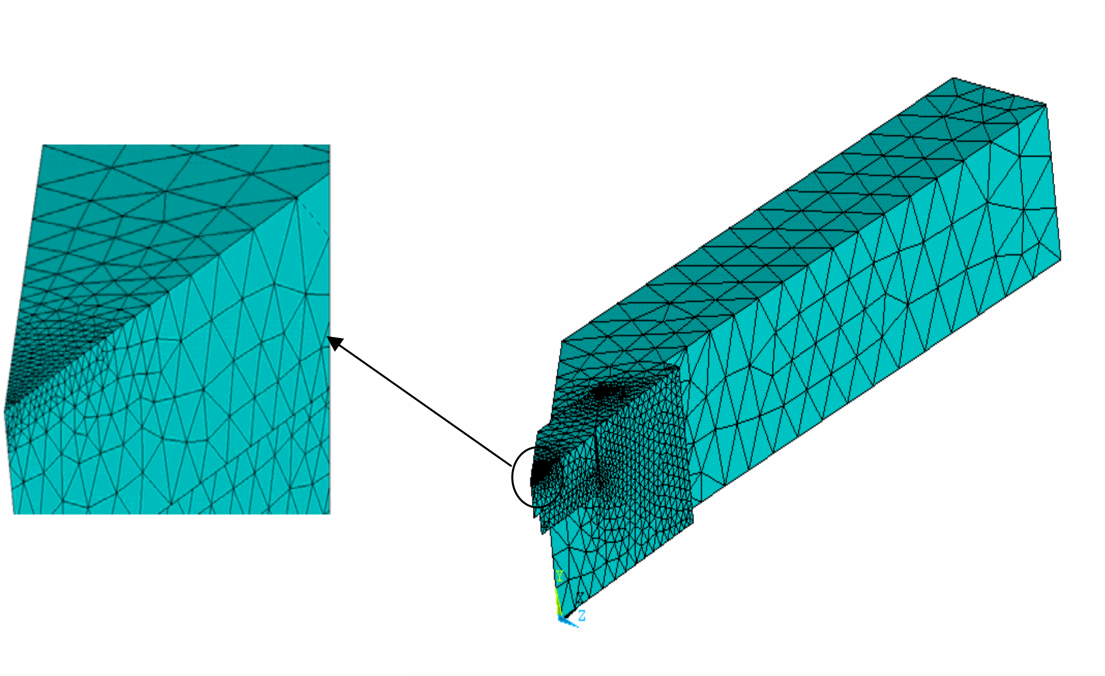


Three Regions in Machining

Thee heat flux on the tool was calculated and applied in the finite element thermal analysis. The temperature history from the analysis was matched with the experimental data to estimate the fraction of heat entering the tool for both conventional and high speeds.



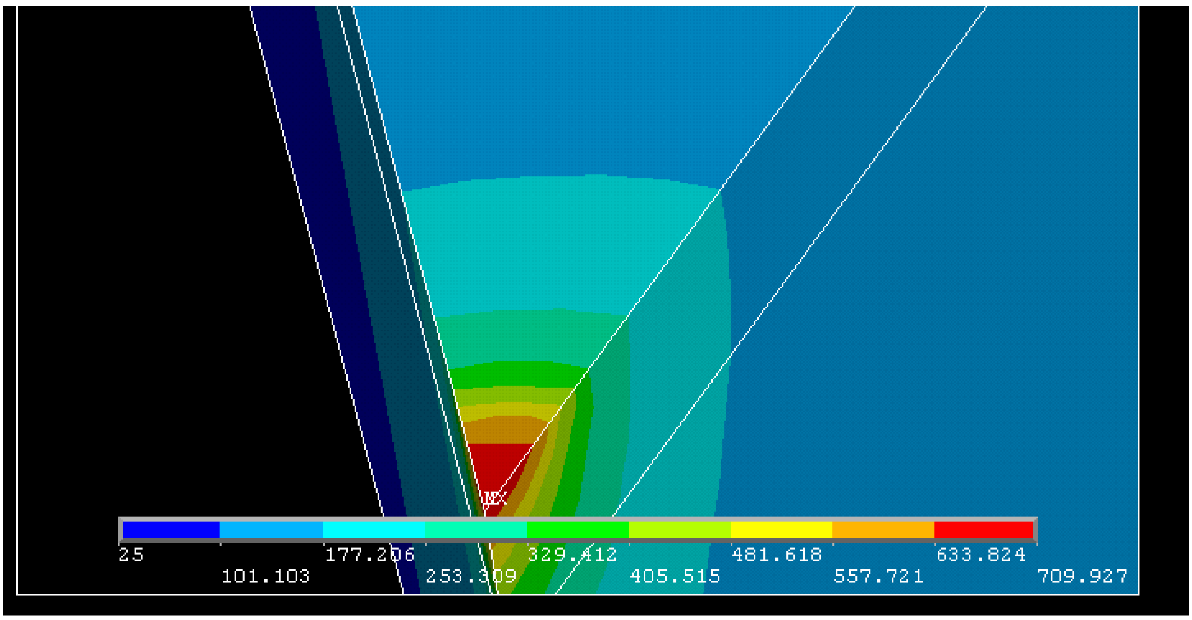
CAD Model of the Tool in Pro-Engineer



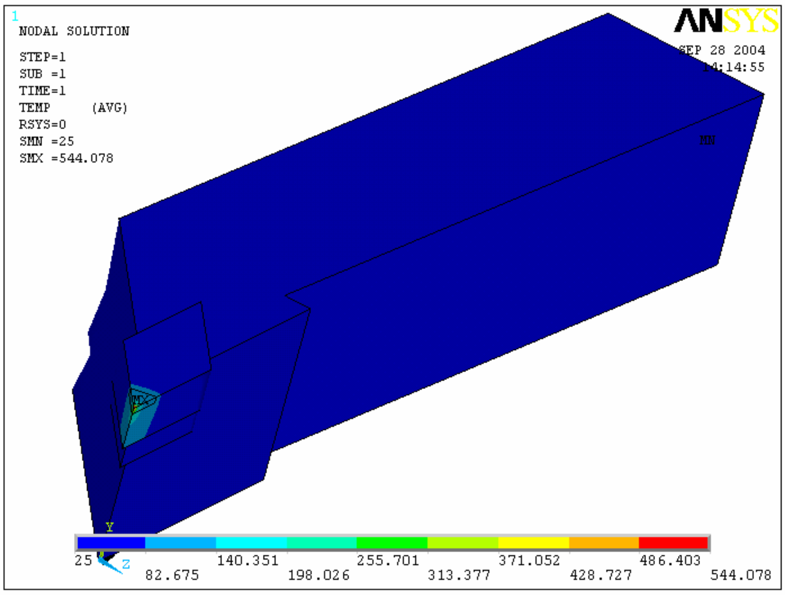
Meshed Tool in ANSYS

Results:

The heat partition into the tool was estimated to be around 21-22% for conventional speeds, whereas for high-speed turning, it was around 14%

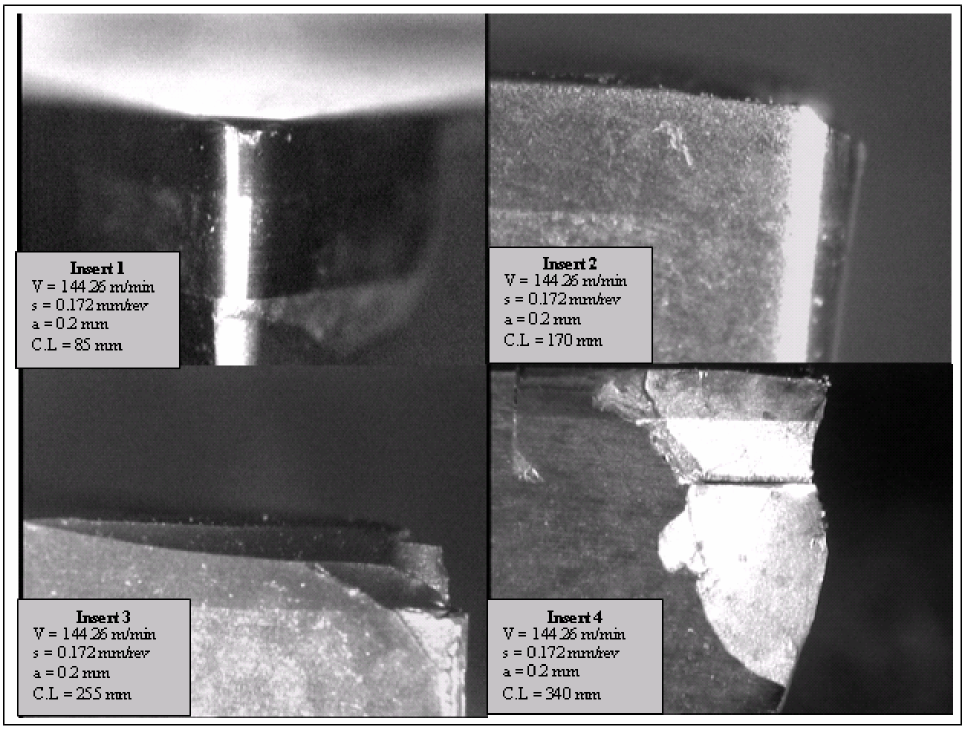


FE Thermal Analysis in ANSYS



Conclusion:

The tool wear, however, was found to be dominated by chipping for both cutting speeds, and could be reduced considerably by reducing the amount of heat entering the tool. Hence it was concluded that in order to improve tool life, tools should be made with materials having low thermal conductivity.



Tool Wear

Publications

N Abukhshim, P Mativenga and **M A Sheikh**, *An investigation of the tool-chip contact length in high speed turning of EN19 steel*, IMechE Proceedings: Journal of Engineering Manufacture - Part B, **218**, 889-903, 2004.

N Abukhshim, P Mativenga and **M A Sheikh**, I*nvestigation of heat partition in High Speed turning of High Strength Alloy Steel*, Int. J. Machine Tools & Manufacture, **45**, 1687-1695, 2005.

Mohammad Usman Ghani, Nuri Abukhashim and **M A Sheikh**, *A Comaprative Study of Heat Partition and Tool Wear in Machining at Conventional and High Speeds*, Submitted for publication in Journal of Advanced Manufacturing Technology, 2006.

N Abukhshim, P Mativenga and **M A Sheikh**, *Heat partition and Temperature Distribution in Metal Cutting: A Review and Implications for High Speed Machining,* Accepted for publication in Int. J. Machine Tools & Manufacture, 2005.

N. Abukhshim, P.T. Mativenga, **M. A. Sheikh** and K.K.B. Hon, *An Investigation of Tool Chip Contact Phenomena in High Speed Turning Using Coated Tools,* Accepted for publication in IMechE Proceedings: Journal of Engineering Manufacture – Part B, 2006.