FINITE ELEMENT ANALYSIS OF EDGE CRACKED BIMATERIAL SYSTEMS UNDER CONVECTIVE COOLING

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INTRODUCTION

- The multi layered structures of dissimilar materials with different mechanical and thermal properties under thermal stresses are used in many engineering applications to protect the base metal from corrosion and other thermal damages.

- For example, the thermal barrier coating of super alloys by ceramics used in jet engines, stainless steel cladding of nuclear pressure vessels.

- The SIFs of bi-material cracks could be obtained by numerical analyses such as
  - the finite element method (FEM) or the boundary element method (BEM).
  - Energy approaches such as the crack closure integral method (Irwin, 1957),
  - the *J* -integral method (Rice, 1968) and
  - the virtual crack extension method (VCE) (Parks, 1974, 1978) are reliable methods for calculating the energy release rate using FEM and BEM.

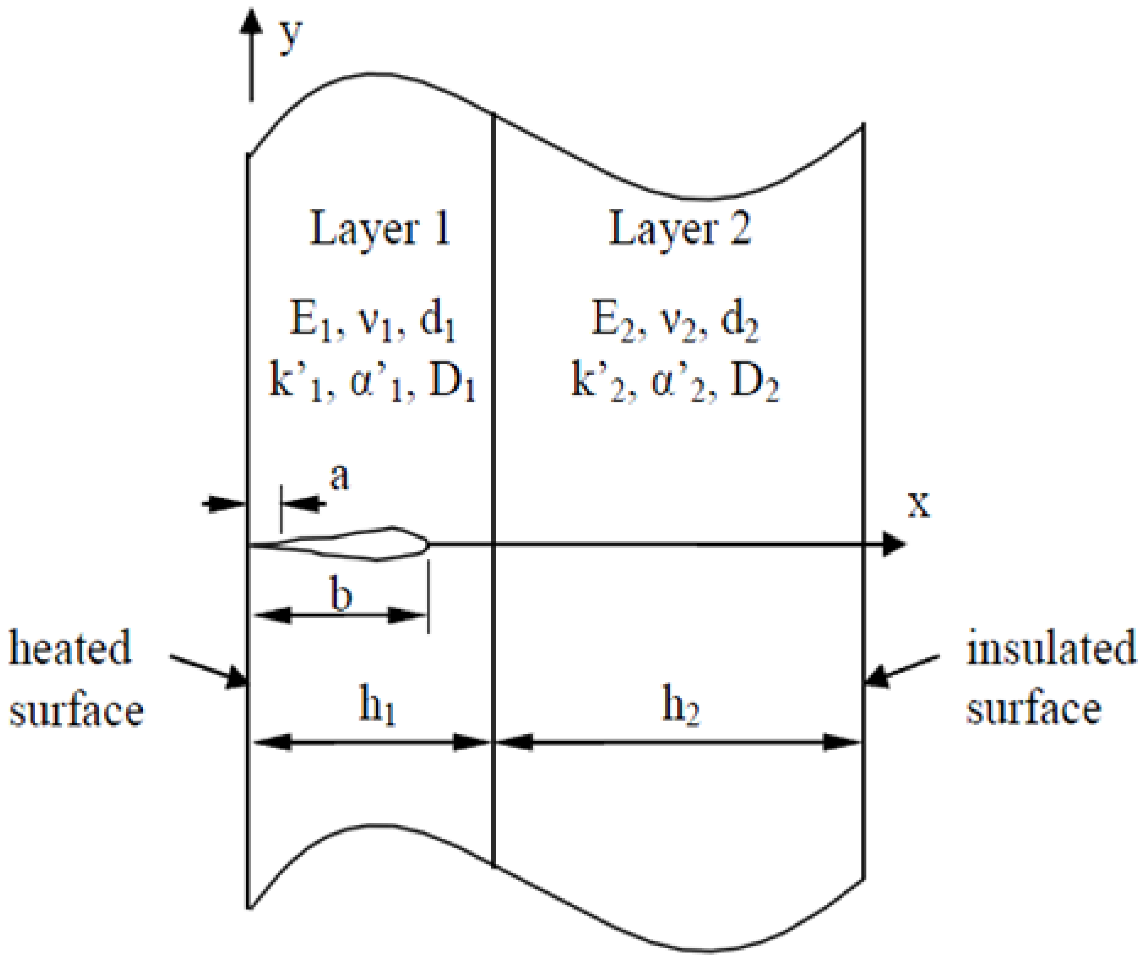


Figure 1 Crack geometry in bi-material systems under surface heating (Rizk and Harari, 2008)

OBJECTIVES

- Analysis of bi-material system containing crack and crack terminating at the interface normal to the interface, which is subjected to cooling on the surface containing the crack.
- To investigate the cracked bi-material systems under thermal cooling by using FEA.
- To compare the ANSYS results with the Analytical data (Rizk 2008).

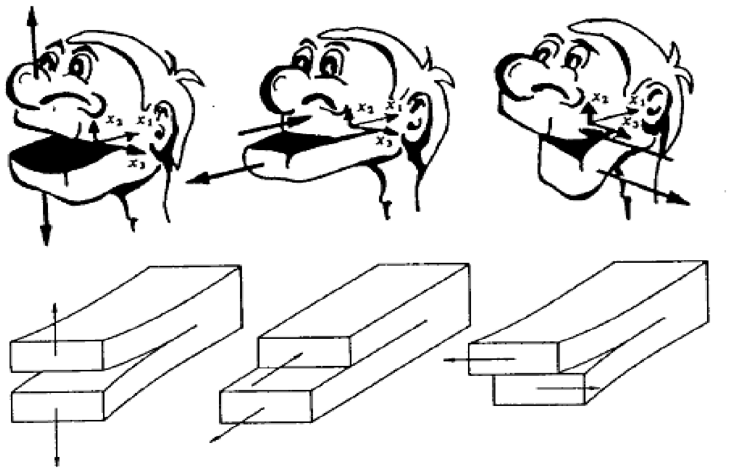
LITERATURE REVIEW

- Fracture Mechanics
- Finite element analysis
- Stress intensity factor
- Interface crack problems

LITERATURE REVIEW(cont.)

1. **Fracture mechanics**

- It deals with the study of how a crack or flaw in a structure propagates under applied loads



The three basic modes of fracture (Wang, 1996)

LITERATURE REVIEW(cont.)

1. Finite element analysis

- Powerful tool
- Preprocessing, analysis, and postprocessing
- Different types of software

a) ANSYS
b) NASTRAN
c) ABAQUS
d) FRANC 2D & 3D and so on.

LITERATURE REVIEW(cont.)

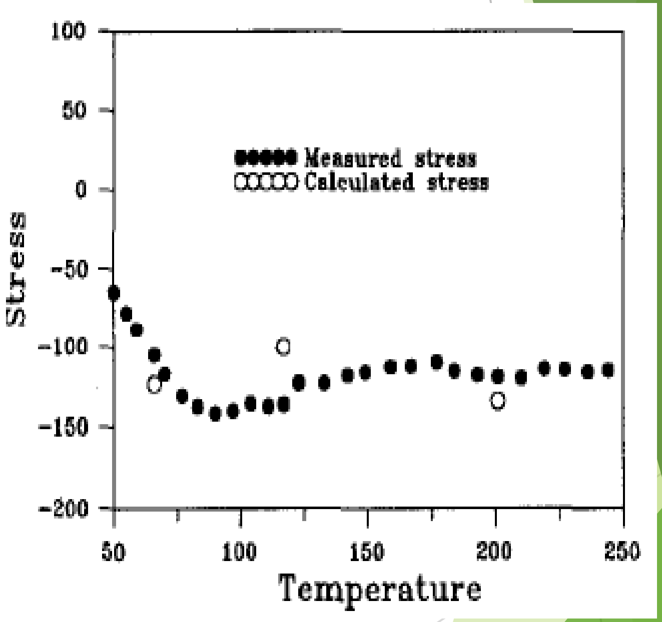
- (Ramesh chandwani, Miles Wiehahm, Chris Timbrell, 2004)

1. fracture mechanics analyses in Ansys
2. ZENCRACK has been interfaced to ANSYS allowing state of the art 3D fracture mechanics analysis to be undertaken.
3. This software reads un cracked finite element model and produce cracked finite element model.

LITERATURE REVIEW(cont.)

- Kug Weon Kim, Nam Woong Kim and Dae-Jin Kang
  Finite element analysis of thermal stress characteristics for CRT

- The stresses decrease as the temperature increases, then the stresses increase with the temperature increasing and the stresses decrease again as the temperature increases



Comparison of calculated and measured stress for panel outer surface(kim,1998))

LITERATURE REVIEW(cont.)

- Crack Analysis
- Calculation of Stress intensity factor

1. De Matos, Moreira, De Castro, 2000
2. SIF for cracked circular hole by FEA
3. software FEMAP and ABAQUS
4. The greater the number of elements (i.e., the mesh refinement), the closer KI result to the reference value

LITERATURE REVIEW(cont.)

- **Two different approaches**

1. Direct method in which the stress intensity factors follow from the displacement field.

2. Indirect method in which the stress intensity factors are determined with other fracture parameters, such as the energy release rate or the Jk integrals.

LITERATURE REVIEW(cont.)

- Stress intensity factors in poroelastic materials have been found by using finite element analysis in FRANC3D.
- The element is created in ANSYS and then exported to the Poroelastic-Enriched FRAC3D (Han, 2009).

LITERATURE REVIEW(cont.)

- Interface crack problems with thermal loading

1. Thermal stresses, one of the main causes of interfacial failure between dissimilar materials.
2. Great residual stress is often caused near an interface between dissimilar materials because of the difference in the coefficient of linear thermal expansion between the two jointed materials.
3. **Ikeda** and **Sun** found SIF by modified virtual crack extension method and the crack closure integral method numerically.

LITERATURE REVIEW(cont.)

- The interfaces between the materials are where failure is most likely to occur when the device is subjected to thermomechanical loading, usually along the device's edges and at corners.

- This is due to inherent weaknesses in interfacial bonds between dissimilar materials and stress concentrations that arise at the bimaterial free surface.

- At present, most commercially available finite element codes are not designed to properly compute stress intensity factors for cracks on bimaterial interfaces without significant modification.

Uniqueness of our problem

- Fracture mechanics + Thermal analysis + FEA
- Fully modelled in ANSYS and analysis also done by ANSYS
- Crack perpendicular to the interface

TRANSIENT THERMAL ANALYSIS

- For each simulation we will use this type of model.
- Depending on the time available, we used two systems of two different materials to obtain results, to study the results and to conclude.

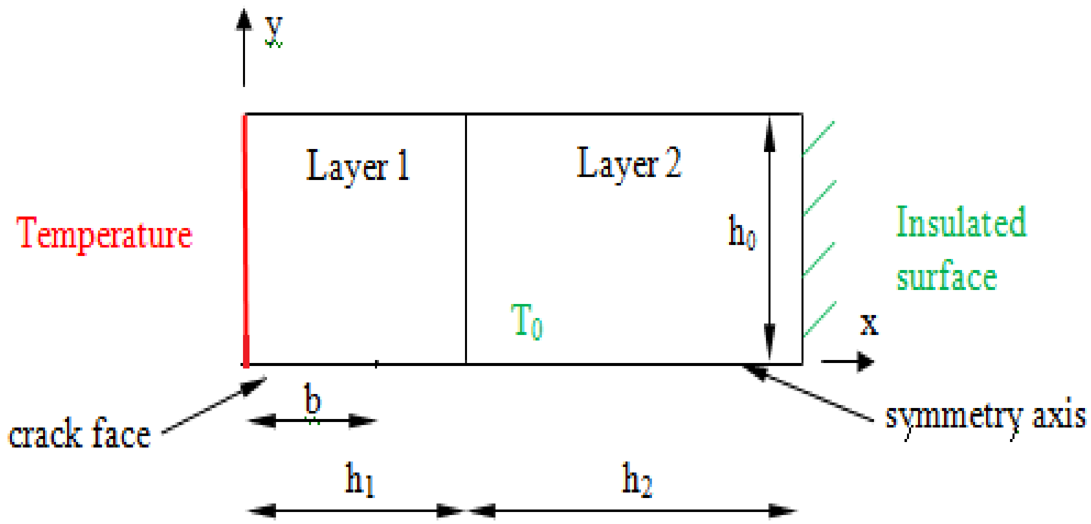


Table 7 - Material Systems

	Layer 1	Layer 2
System A	Stainless steel	Ferritic steel
System B	Ceramic	Ferritic steel

Table 9 - Ratio of properties (Rizk and Hrairi, 2009)

Bimaterial systems	k'_2/k'_1	D_2/D_1	α'_2/α'_1	E2/E1	ν'_2/ν'_1	c_2/c_1
A	3	3	0.75	1	1	1.02
B	3.385	4.07	2.2939	0.6111	1	0.4

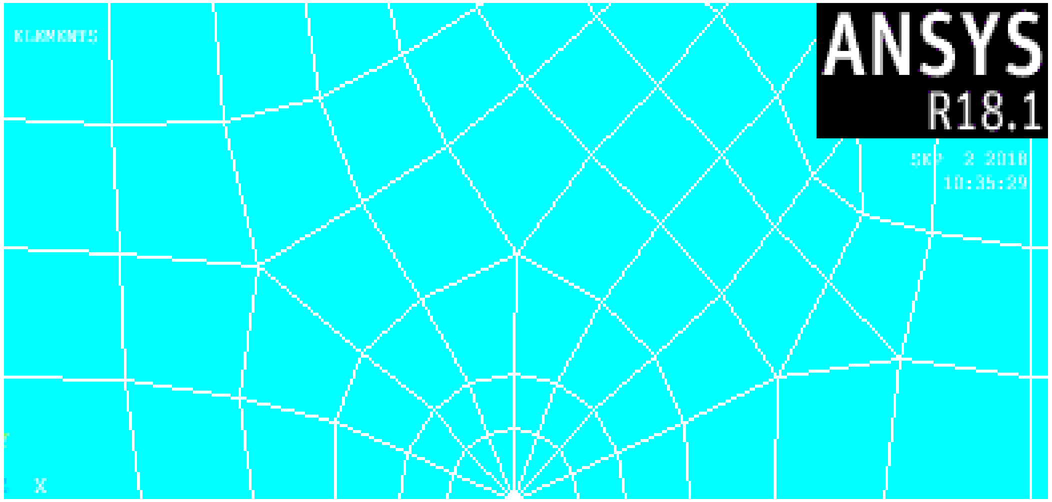
Table 8 Material Properties

Material properties	Stainless Steel	Ceramic	Ferritic Steel	Units
Young's modulus : E	206	337	206	GPa
Poisson's ratio : ν	0.3	0.3	0.3	-
Mass density : d	8000	3800	7850	$kg.m^{-3}$
Thermal conductivity : k'	13.4	11.9	40.2	$W.m^{-1}.K^{-1}$
Thermal expansion : α'	16×10^{-6}	5.2×10^{-6}	12×10^{-6}	K^{-1}
Thermal diffusivity : D	3.48×10^{-6}	2.57×10^{-6}	10.44×10^{-6}	$m^2.s^{-1}$
Specific heat capacity : c	481	1218	491	$J.kg^{-1}.K^{-1}$

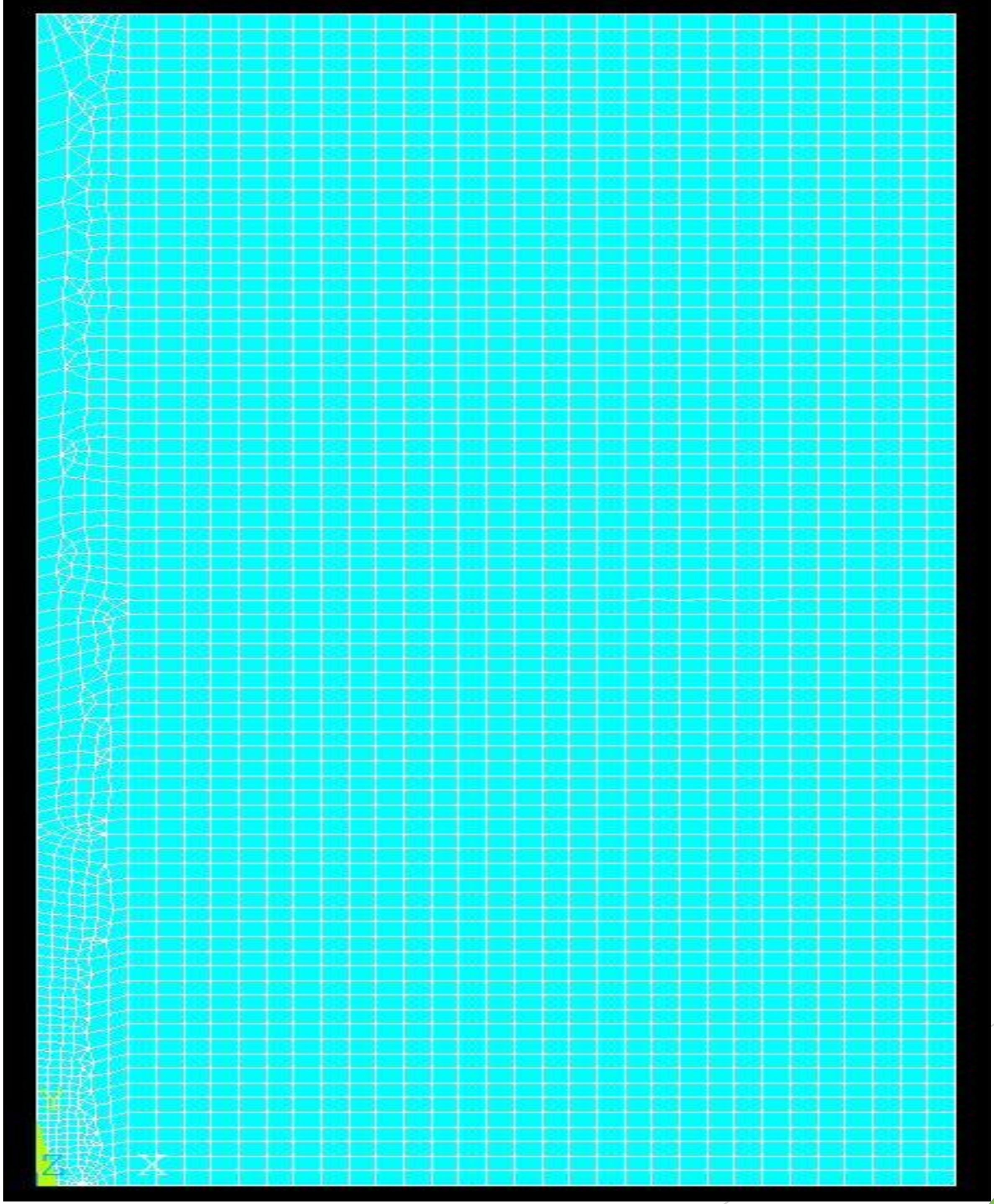
Plane 77 is the element used for the analysis

Thermal properties values for both layers are added in ANSYS

Two areas are glued together and then meshing was done

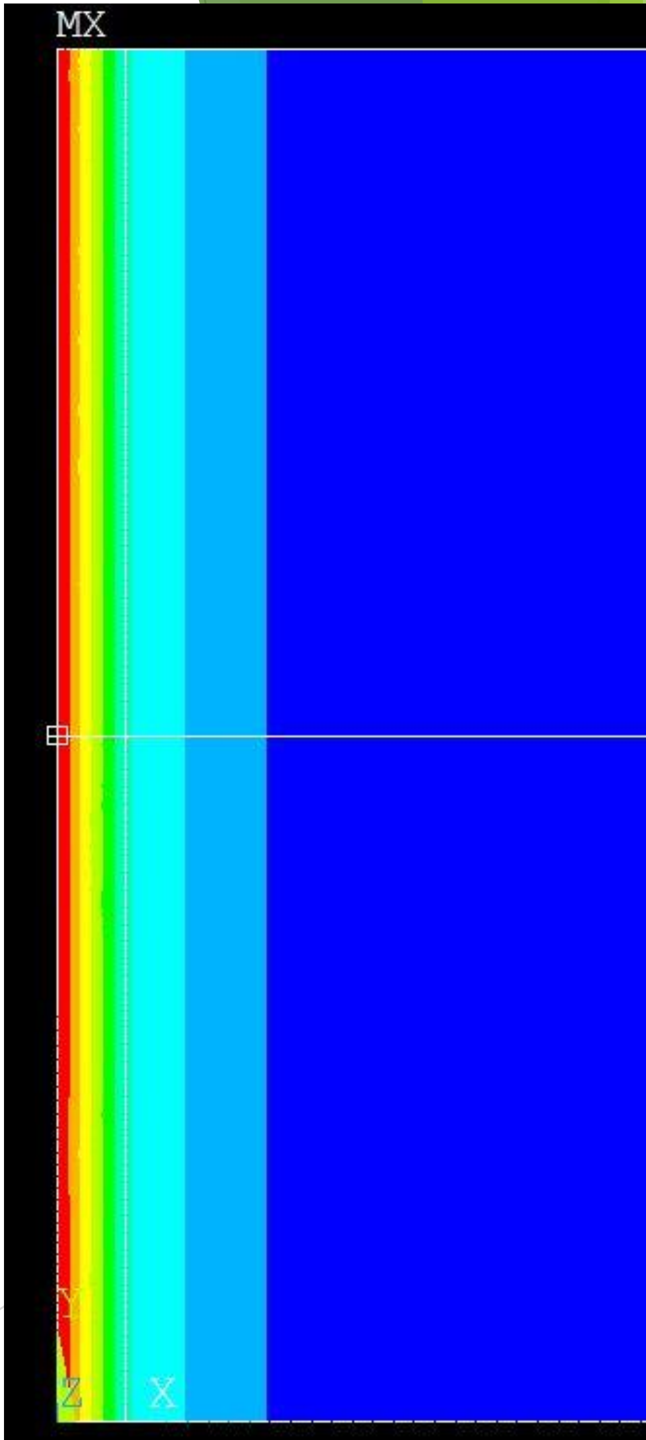


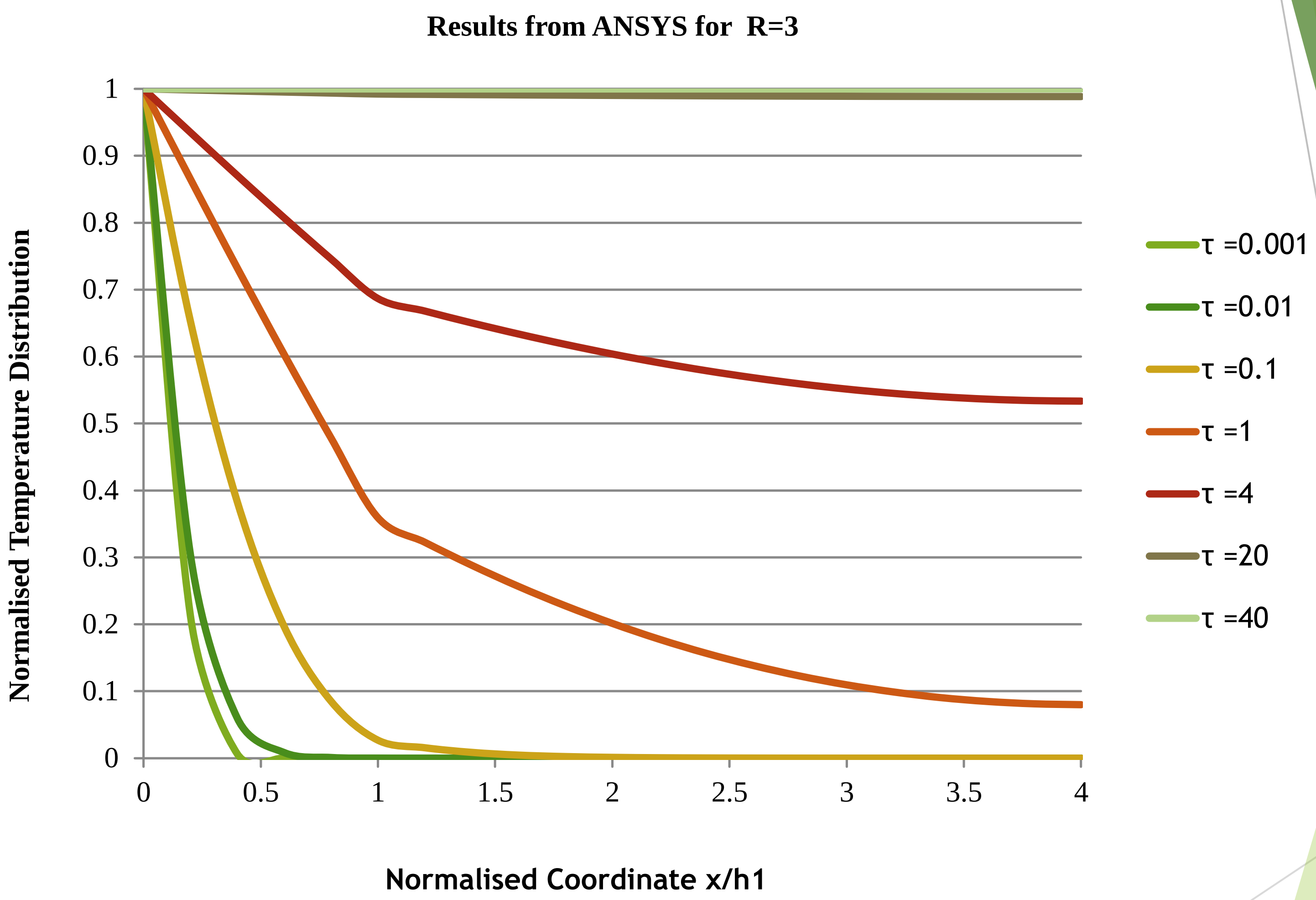
Finite Element Meshing around crack tip

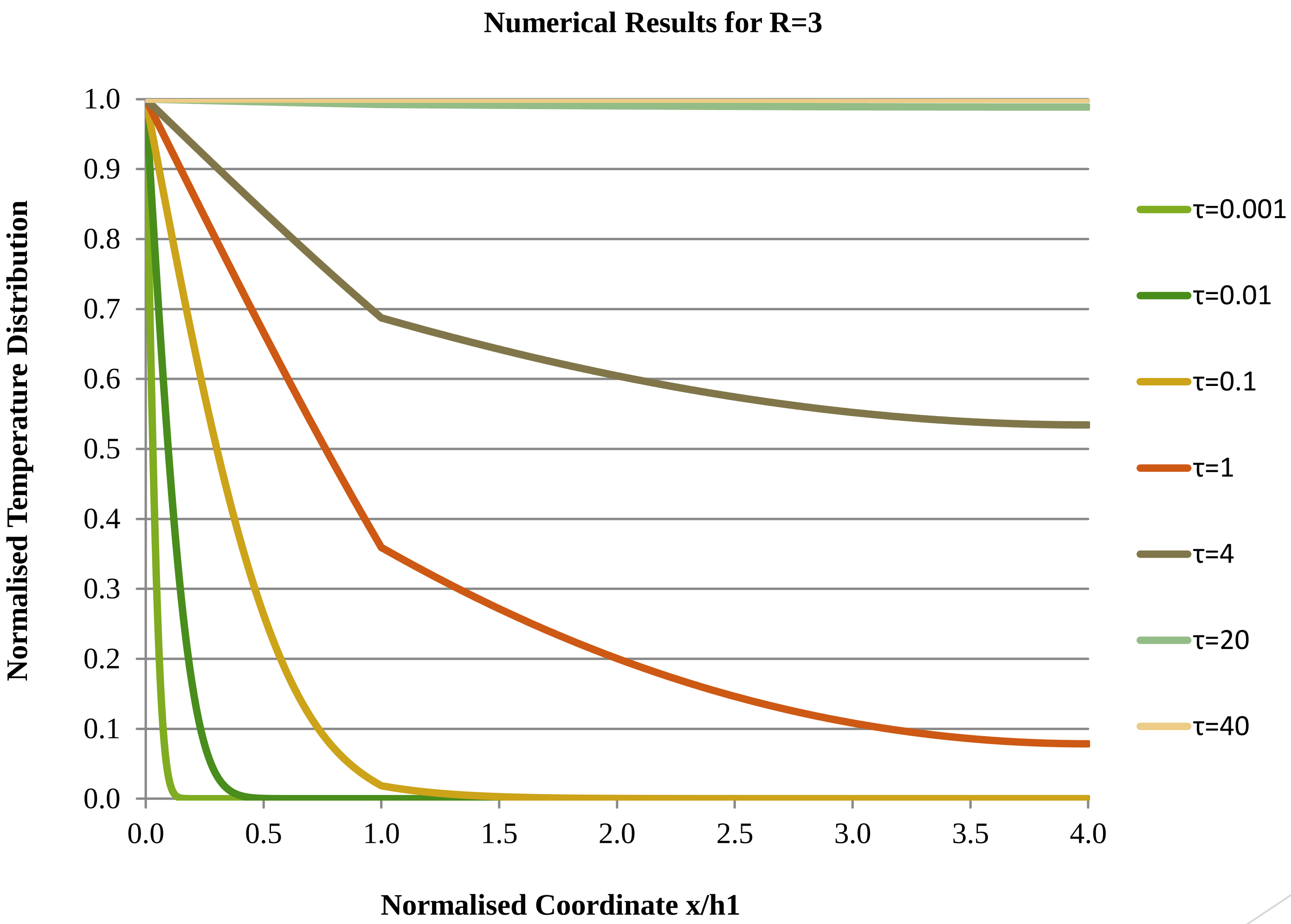


Transient Temperature Distribution

- Temperature on the crack face = $-500°\mathrm{C}$
- The face $x = h_1 + h_2$ is insulated
- Temperature Distribution for various timings are shown in the results
- Normalised temperature θ/θ_0 is calculated by using a formula $\theta = T(x,t) - T_0$and $\theta_0 = T_a - T_0$. In Ansys, the uniform temperature $T_0 = 22°c$.




Results from ANSYS for R=3
Normalised Temperature Distribution
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Normalised Coordinate x/h1
τ =0.001
τ =0.01
τ =0.1
τ =1
τ =4
τ =20
τ =40


Numerical Results for R=3
Normalised Temperature Distribution
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Normalised Coordinate x/h1
τ=0.001
τ=0.01
τ=0.1
τ=1
τ=4
τ=20
τ=40

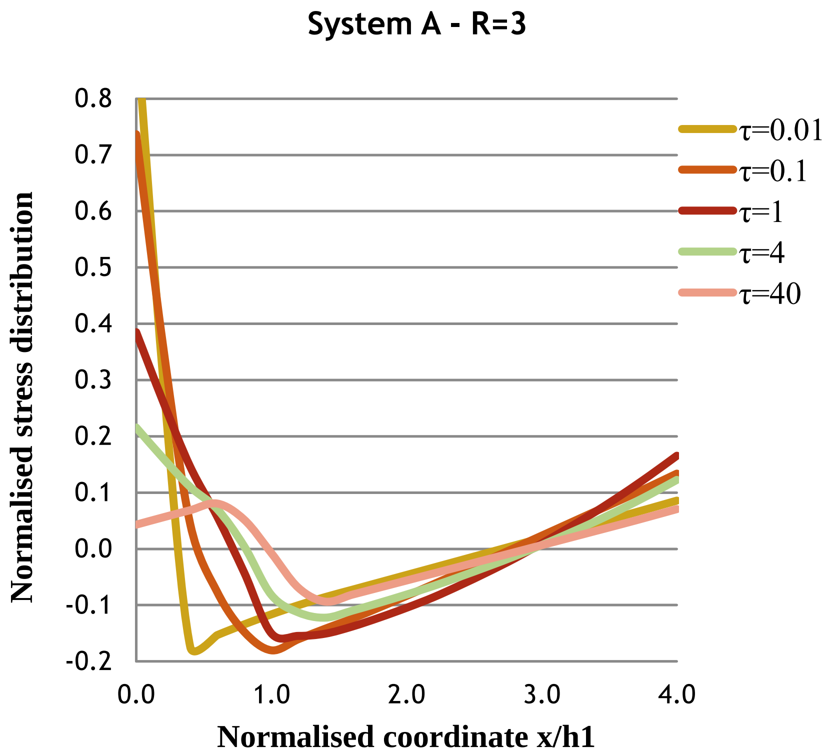
STRUCTURAL ANALYSIS

- Analysis in ANSYS had to be switched from thermal analysis to structural analysis to find the thermal stress and stress intensity factor (SIF)
- All the structural properties are inserted
- Elements switched from thermal to structural
- Temperature distribution from the thermal analysis are extracted to do the structural analysis
- Stress distribution and SIF are calculated in ANSYS
- Normalized transient thermal stresses are calculated by σ_{yy}^{T} which is calculated from Ansys and divide by σ_0^T where

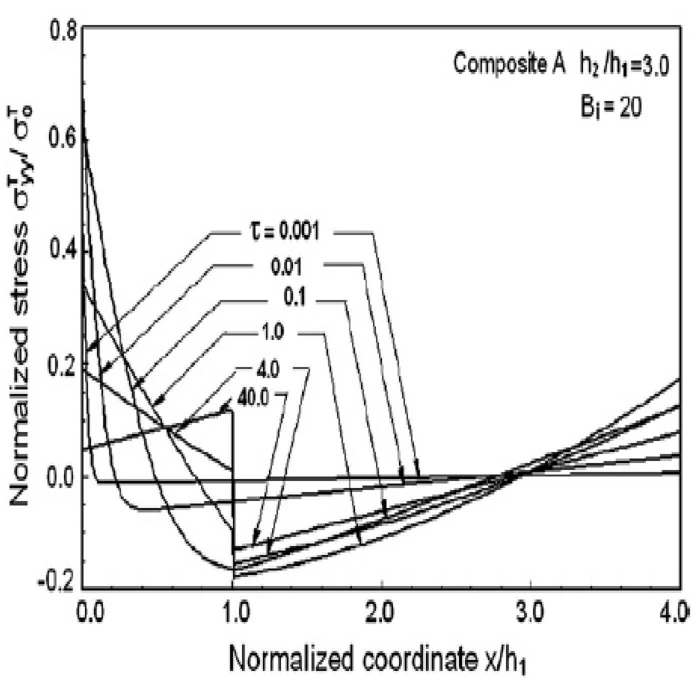
  $\sigma_0^T = -E_1 \alpha_1 \theta_0 / (1 - \vartheta_1)$. (Rizk 2008)
- Normalised stress intensity factor is calculated by using $K(b)/\sigma_0^T\sqrt{b}$ where b is the crack length.
- The results obtained are shown

Comparison between analytical and ANSYS results of system A – R = 3

ANSYS

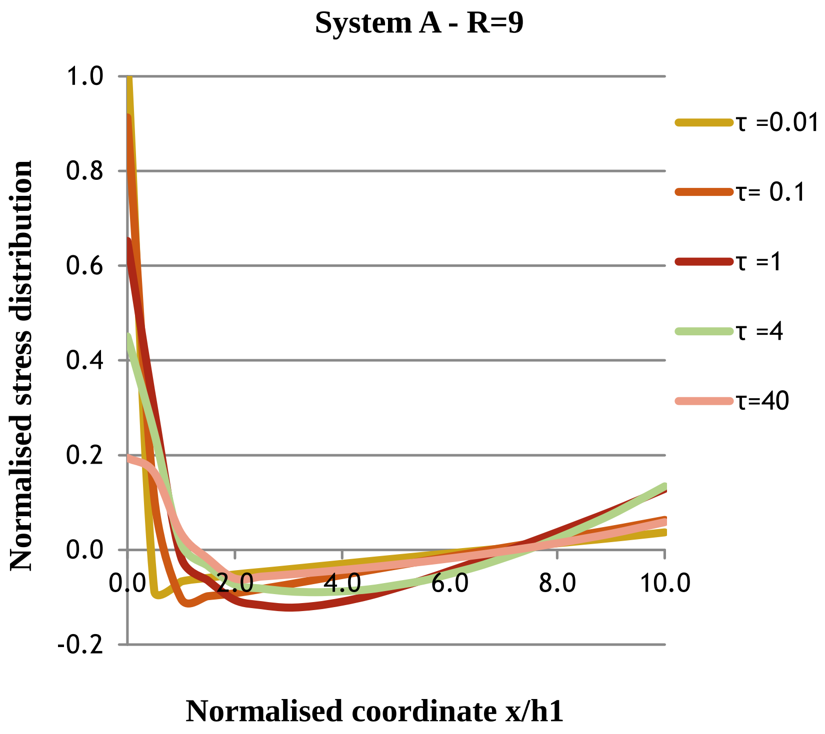


ANALYTICAL

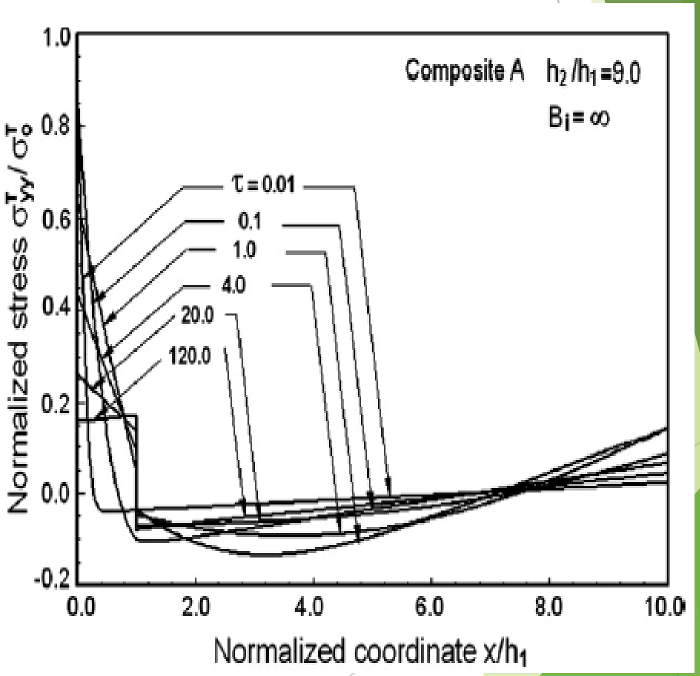


Comparison between analytical and ANSYS results of system A – R = 9

ANSYS

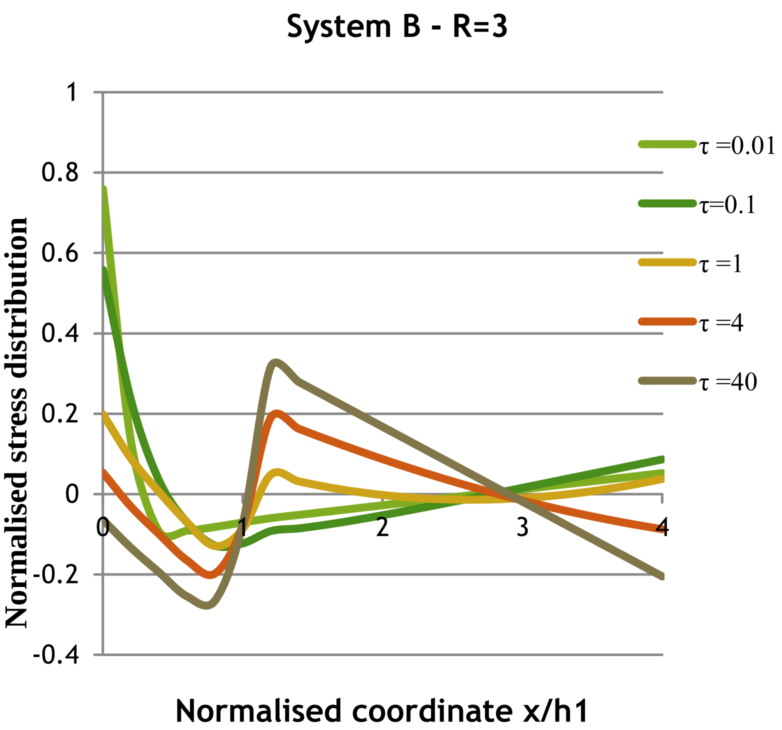


ANALYTICAL

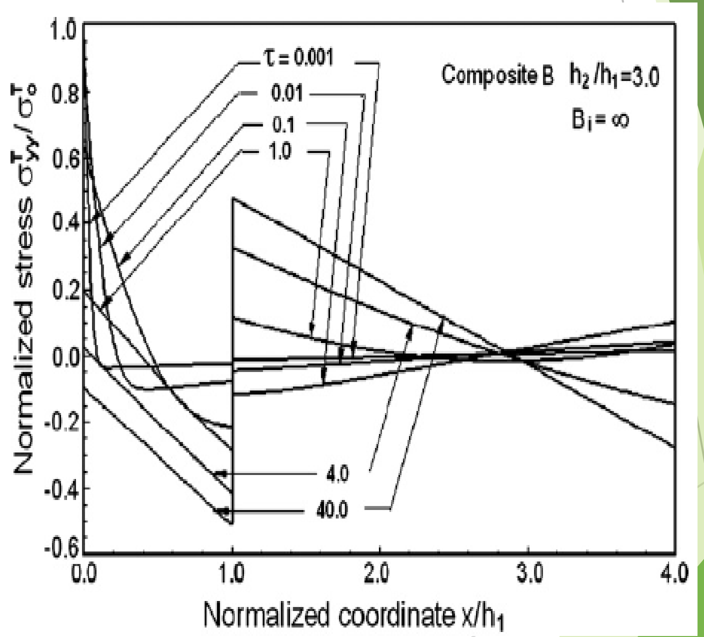


Comparison between analytical and ANSYS results of system B – R = 3

ANSYS

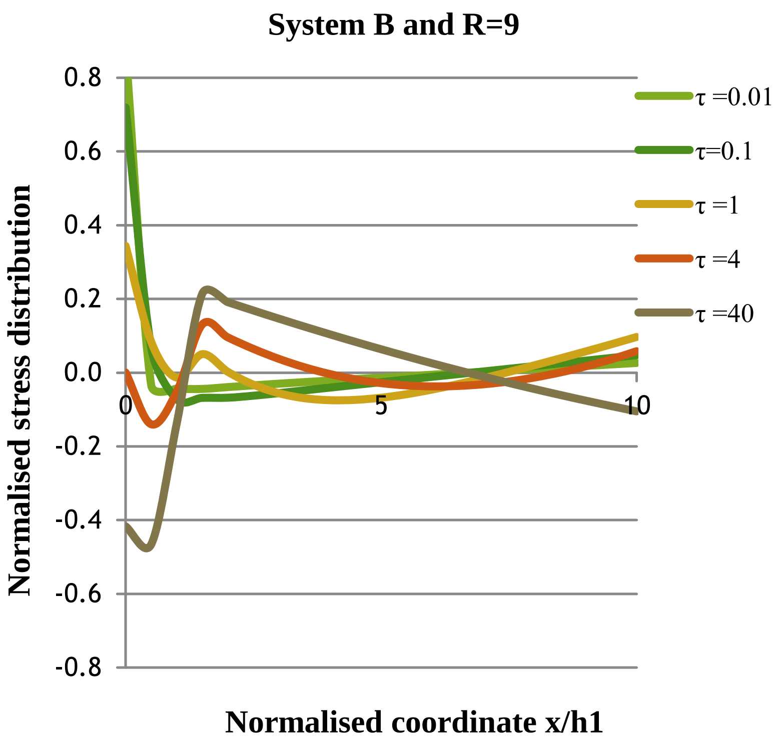


ANALYTICAL



Comparison between analytical and ANSYS results of system B – R = 9

ANSYS



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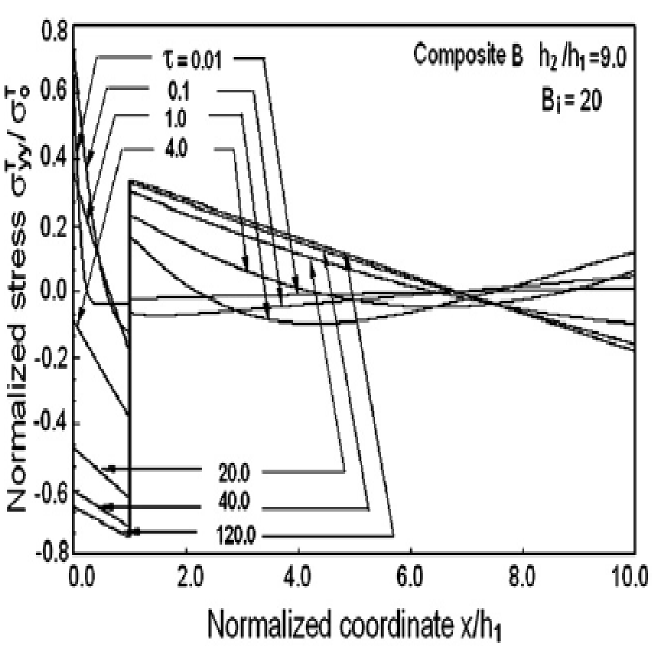
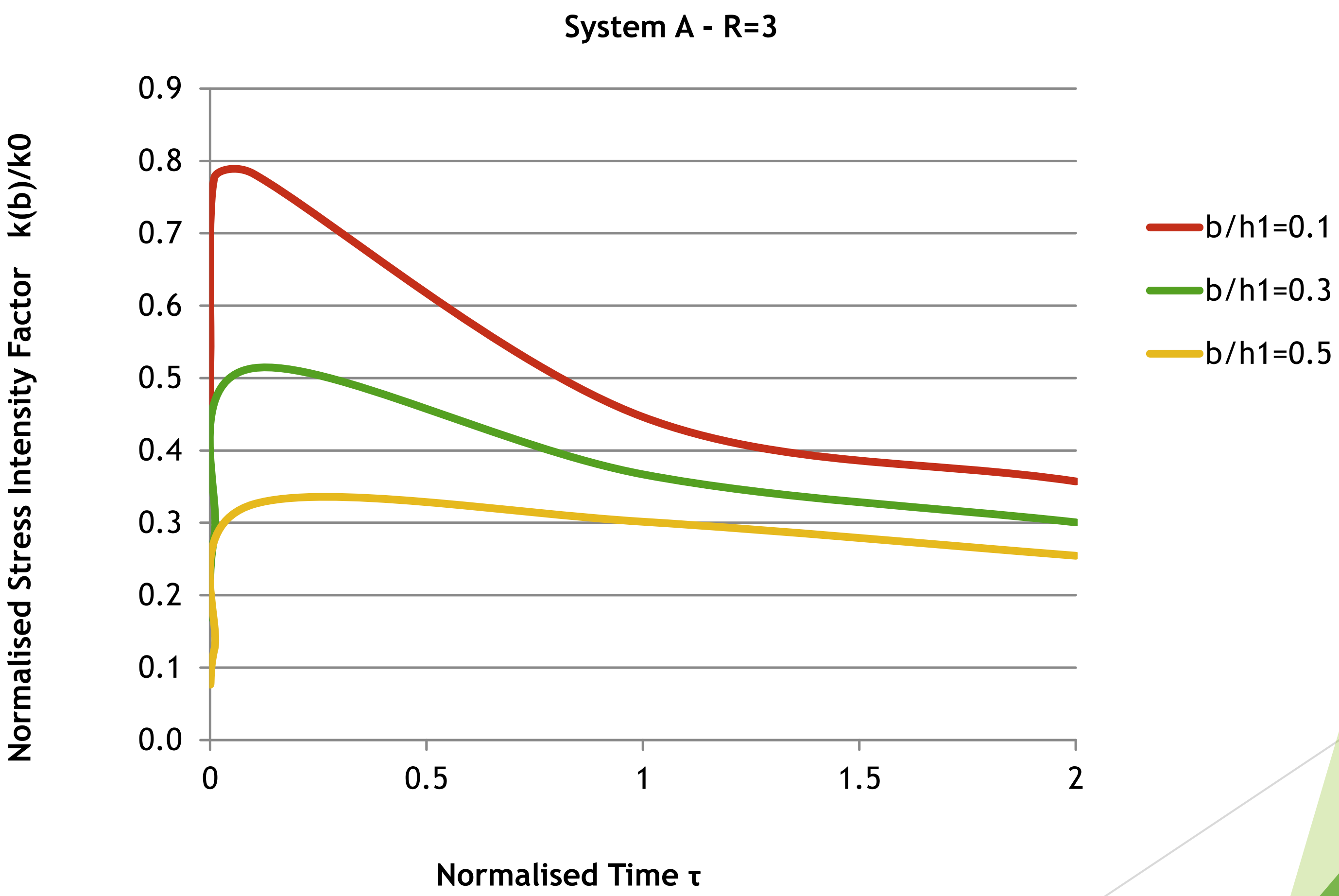
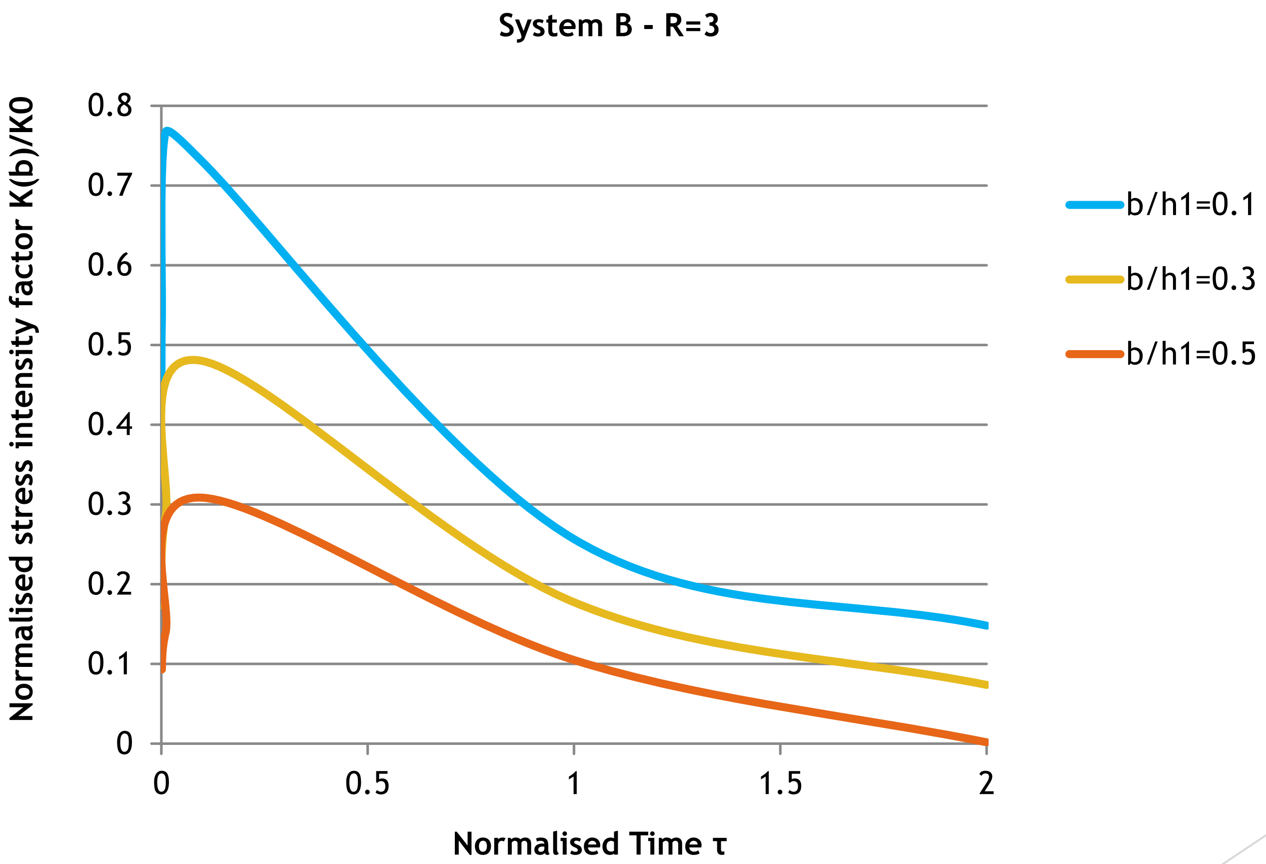


Variation of Stress Intensity Factor with Different Normalized time of system A

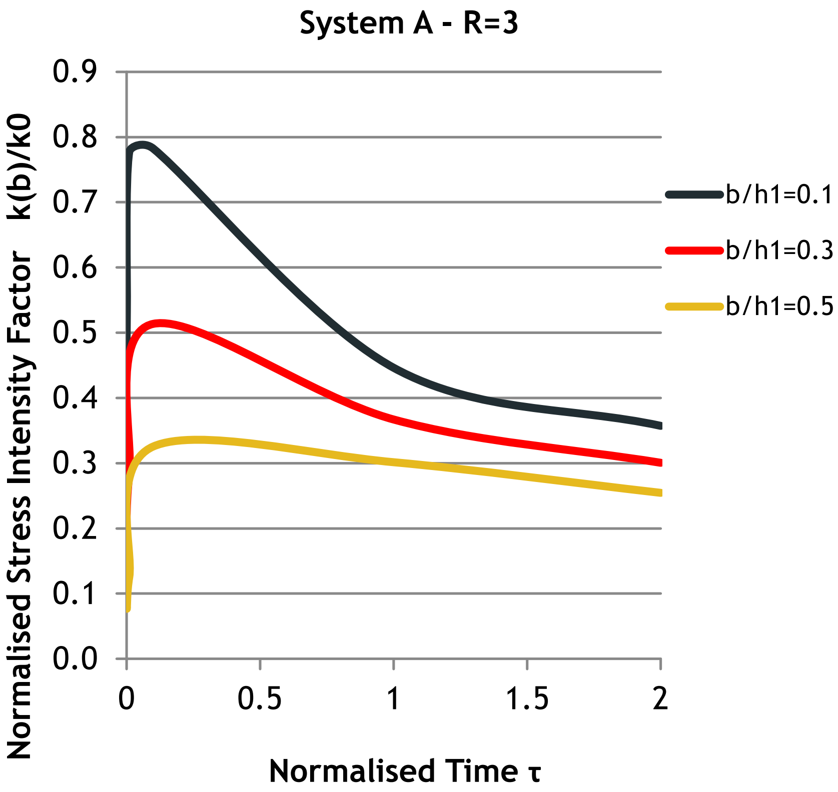


Variation of Stress Intensity Factor with Different Normalized time of system B

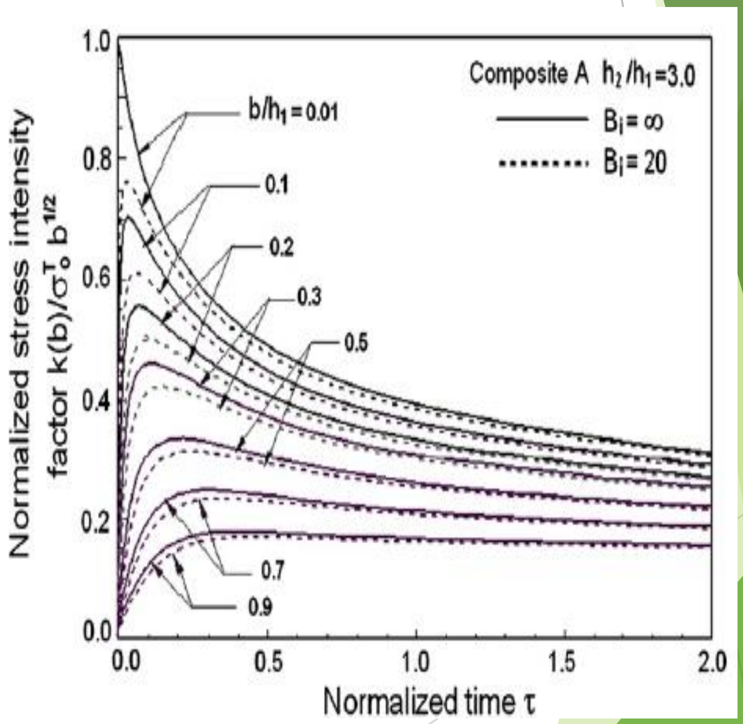


Comparison between analytical and ANSYS results of system A

ANSYS

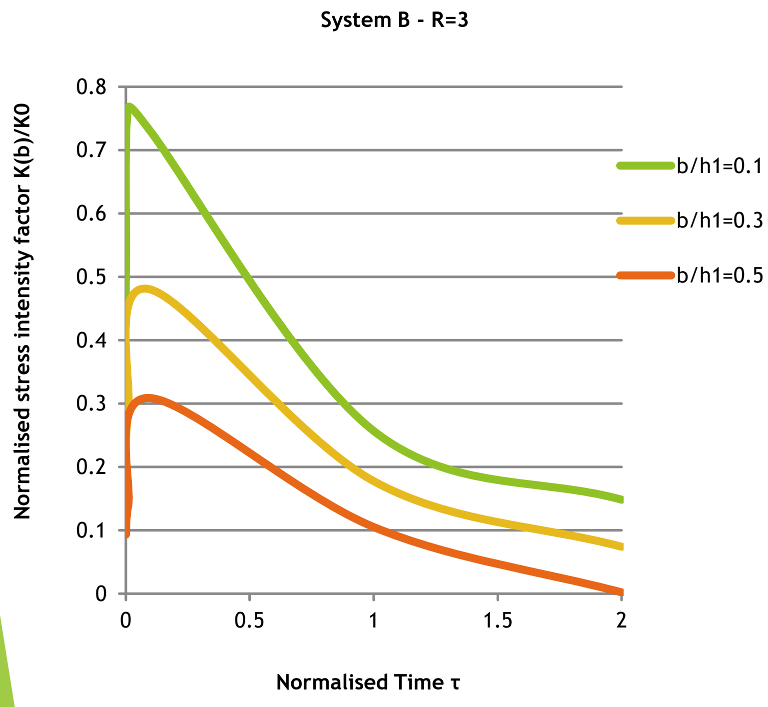


ANALYTICAL

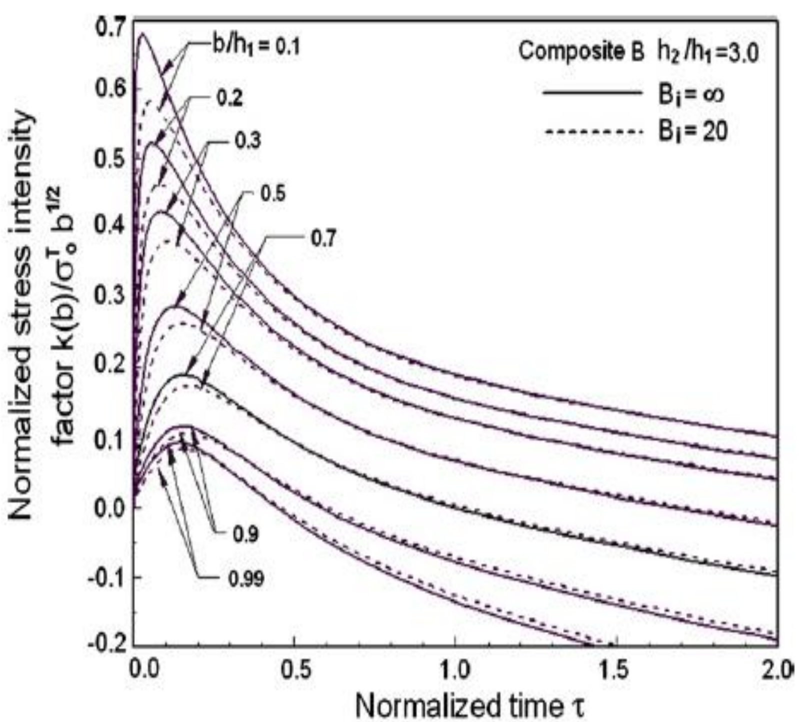


Comparison between analytical and ANSYS results of system B

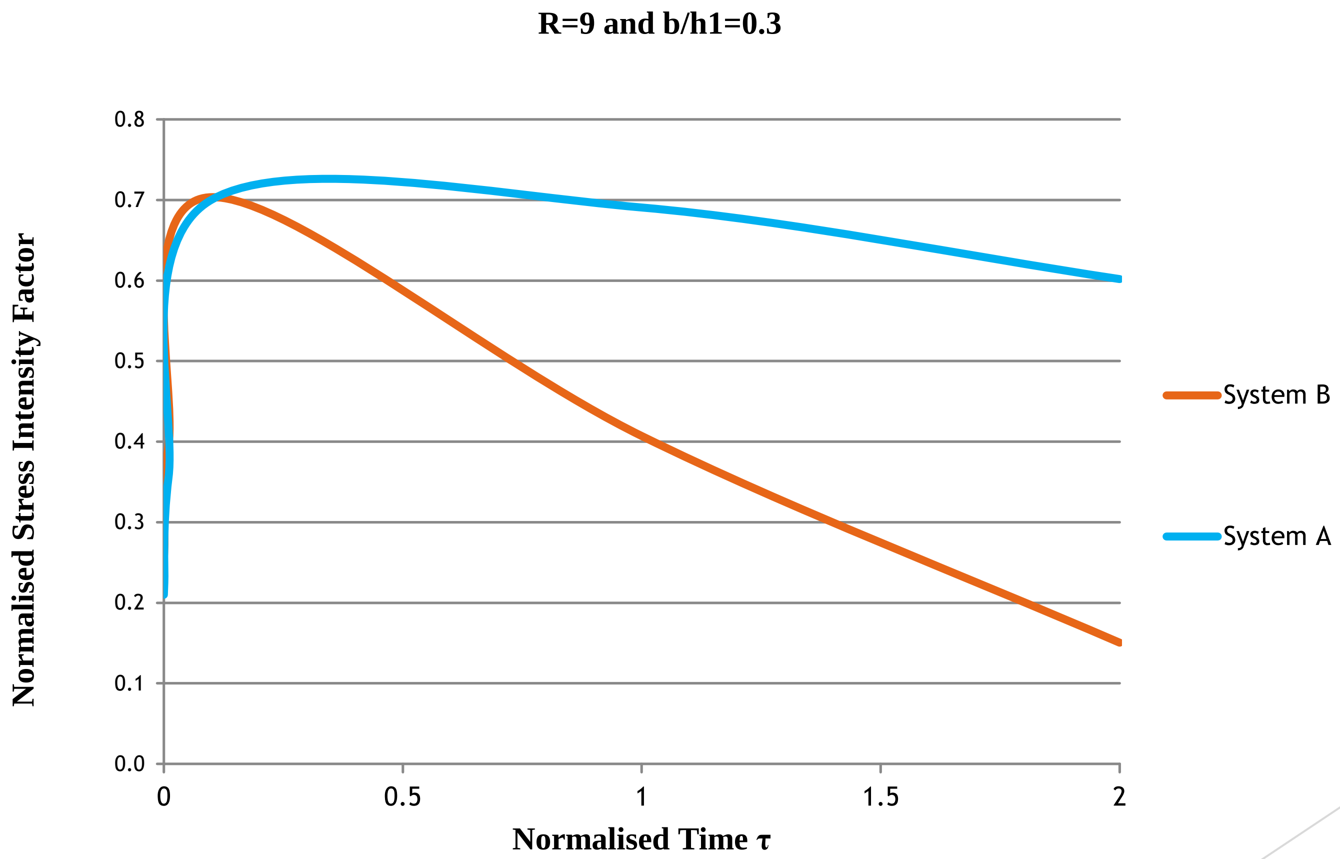
ANSYS



ANALYTICAL



Comparison between system A and system B for R = 9



CONCLUSION

- The ansys results are presented for two different biomaterial systems
- System A has same mechanical properties but different thermal properties whereas System B has different thermal and mechanical properties
- Using couple method, analysis were performed to solve the problem of thermal stresses.
- Effect of varying temperature of edge crack face on thermal stresses was seen.
- The variation between the thermal result is due to the fact that we don't know the actual temperature that has been used in the analytical data.
- But for ANSYS we have to specify temperature for every case.

- In ANSYS stress intensity factor is calculated by KCAL command.
- Even though the values are slightly different from the analytical date, but it follows similar trend because we cant assume the height of the plate is infinity whereas in analytical results, it is assumed as infinity.
- The height of the plate affects thermal stress formed in the plates. Due to the SIF also affected.

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