SIMULATED THERMAL ANALYSIS OF 8Y-PSZ/NICRALY COATING OVER ALSI ALLOY

A. K. Saini*

Abstract: *Zirconia (ZrO_2) is found to be of great interest in the field of research of thermal barrier coatings (TBCs) particularly due to its low thermal conductivity. The present analysis in this paper reveals the simulation based analysis of application of yttria stabilized (partially 8% by weight) zirconia coating applied over an AlSi (12% by weight) alloy using an intermediate bond coat of NiCrAlY. Heat penetration reduction effect was analyzed for different thicknesses of the top layer of zirconia with constant bond coat thickness. Simulation was also carried out to investigate a particular TBC set up for different operating temperatures. The results obtained clearly showed that this particular TBC could have significant effects in reducing heat loss through penetration from the hot media and increasing thermal efficiency of the high temperature engineering components, along with increase in the life of the components.*

Keywords: *Yttria partially stabilized zirconia (Y-PSZ), NiCrAlY, Thermal barrier coating (TBC), Simulation, Thermal behavior*

*Assistant Professor, Department of Mechanical Engineering, Panjab University SSG Regional Centre, Hoshiarpur (Punjab) INDIA

1. INTRODUCTION

Increase in the thermal efficiency of the engineering devices, like internal combustion engines or gas turbines, is restricted due an important factor of heat loss from the hot working media. However, if this heat loss is reduced by applying a fine coating of a suitable material of extremely low thermal conductivity over the substrate material of piston in case of IC engines or blade in case of gas turbines, then penetration of heat from within the hot media into the substrate can be restricted to an appreciable extent which would directly result into a hike in the thermal efficiency of the system, decrease in the cooling load of system and increase in life of the substrate by lowering the temperatures within it. Such a coating of low thermal conductivity has been referred to as thermal barrier coating and worldwide, the researchers have been working in the development of suitable coating materials of such kind. Application of yttria (Y_2O_3) stabilized zirconia as TBC with a suitable metallic interlayer has proven to be effective in this context due to phase stability also [1].

In the present investigation, finite element modeling based simulation was carried out for a substrate material of AlSi (12% Si by weight) alloy overcoated with Y-PSZ layer (8% yttria by weight) and an intermediate bond coat of NiCrAlY, using commercial ANSYS code. The model was then simulated against some typical operating conditions so as to determine the transient temperatures within the substrate and compare the distribution with that obtained in case of transient thermal simulation of uncoated substrate.

2. METHODOLOGY

The part geometry considered for the analysis was a quarter part of a 5 mm thick and 80 mm diameter cylindrical disc. This model was taken as an uncoated substrate. To analyze the effect of TBC, six other similar models were generated respectively with top flat layers of 150, 300, 600, 900, 1200 and 1500 microns but all with an intermediate layer of constant thickness of 150 microns. The top layer, intermediate layer and 5 mm thick substrate in each coated model were assigned the thermal properties viz. isotropic thermal conductivity (k), density (ρ) and specific heat (c), of respectively 8Y-PSZ, NiCrAlY and AlSi (12% by weight) as stated in Table 1 [2-3]. The uncoated 5 mm thick model was assigned the material properties of AlSi (12% by weight) itself as substrate material.

Table 1: Typical values of properties of materials used as TBC, bond coat and substrate

Material	k (W/mK)	ρ (kg/m^3)	c (J/kgK)
8% Y_2O_3-ZrO_2	1.05	5650	483
NiCrAlY	95	8210	468
AlSi (12 wt. %)	150	2660	977

Fig. 1 shows typical meshing of a model coated with 300 microns thick 8Y-PSZ layer and 150 microns thick NiCrAlY layer (referred to as 300/150 model). In the thermal analysis, thermal elements with eight nodes and of the type SOLID70 were used.

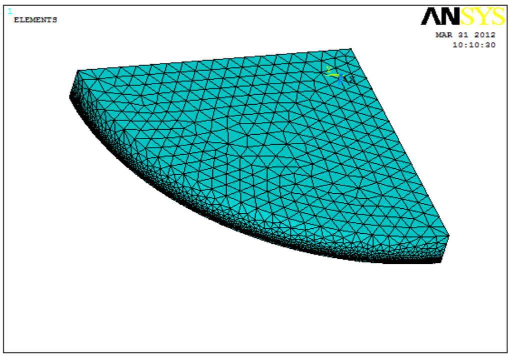


Fig. 1: Meshing of the model

The coated free surface was considered to be exposed to typical convection conditions of high temperature environment as 923 K and convection coefficient as 800 W/m^{2}K while the free flat surface opposite to it was imposed convection conditions of 300 K and 1392 W/m^{2}K [4-5]. Similar conditions were used for either flat surface of uncoated model. Furthermore, an initial uniform temperature of 300 K was assigned for each model under investigation. Finally, transient state analysis was performed for each model and the temperature distribution was observed after 5 seconds of thermal loading. Also, 300/150 model was tested for different operating temperatures of high temperature environment ranging from 400 K to 1800 K with the intervals of 200 K keeping remaining conditions as such.

3. RESULTS AND DISCUSSION

Fig. 2 shows temperature distributions along the thickness between two flat free surfaces after 5 seconds of convection conditions exposure, for one uncoated model and six coated models.

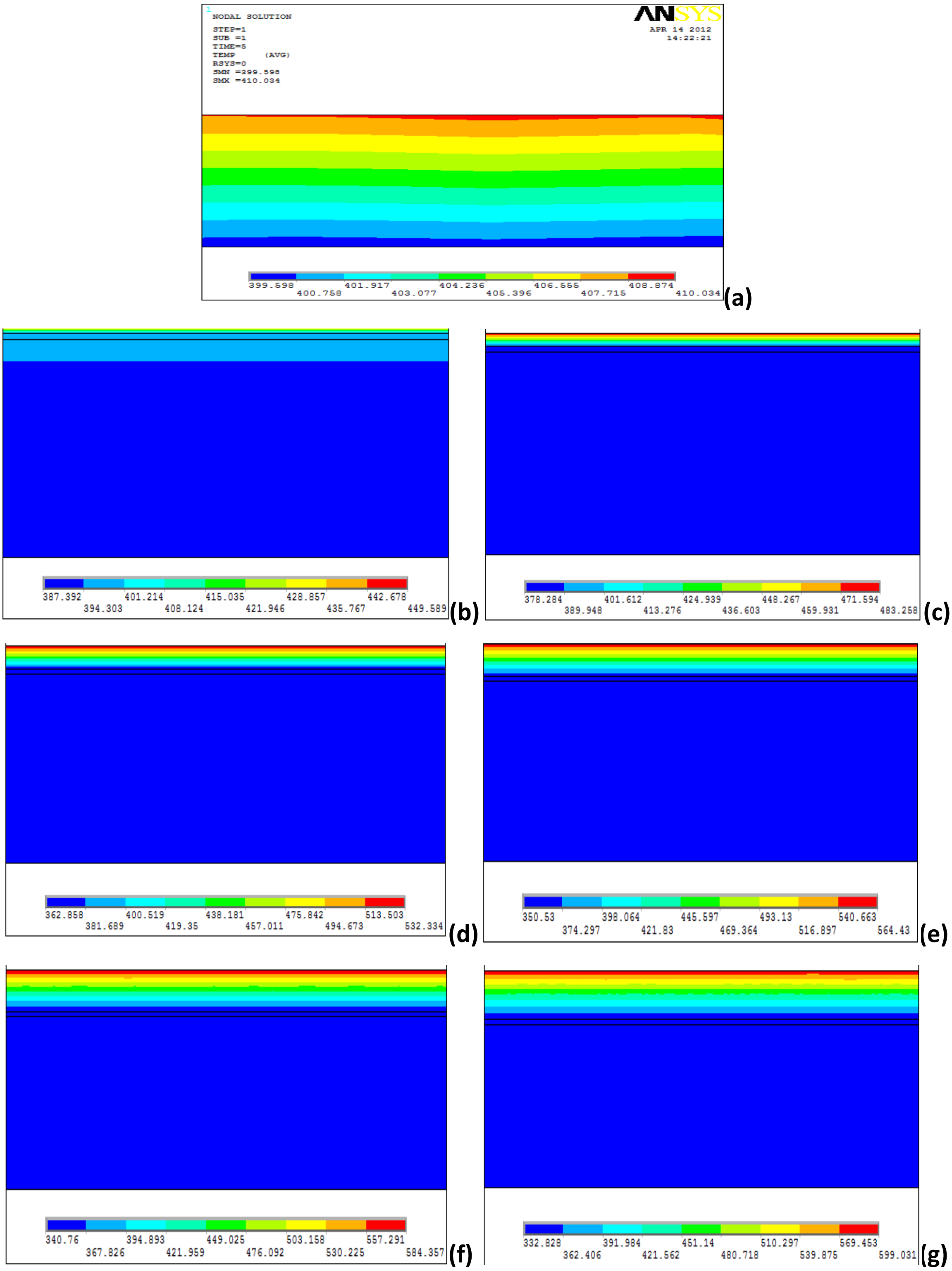


Fig. 2: Temperature distribution along thickness after 5s of thermal loading for (a) uncoated model; (b) 150/150 model; (c) 300/150 model; (d) 600/150 model; (e) 900/150 model; (f) 1200/150 model; (g) 1500/150 model

Using the simulation results of Fig. 2, percentage increases in coating top surface temperature were evaluated as compared to uncoated model for different thicknesses of TBC and are plotted in Fig. 3.

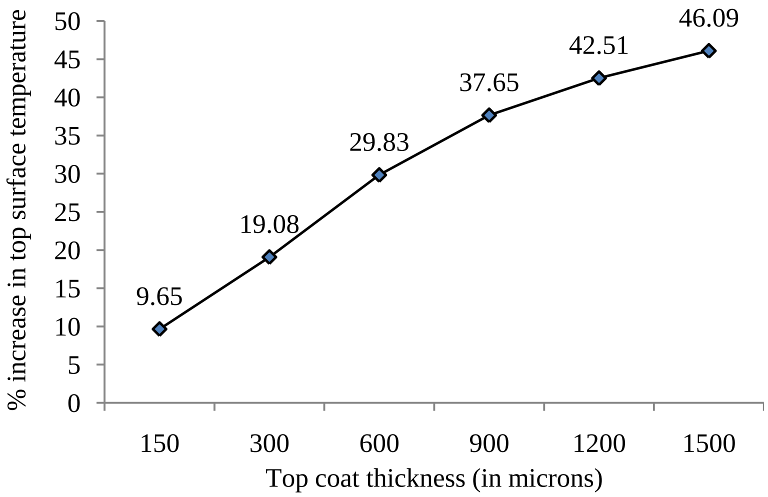
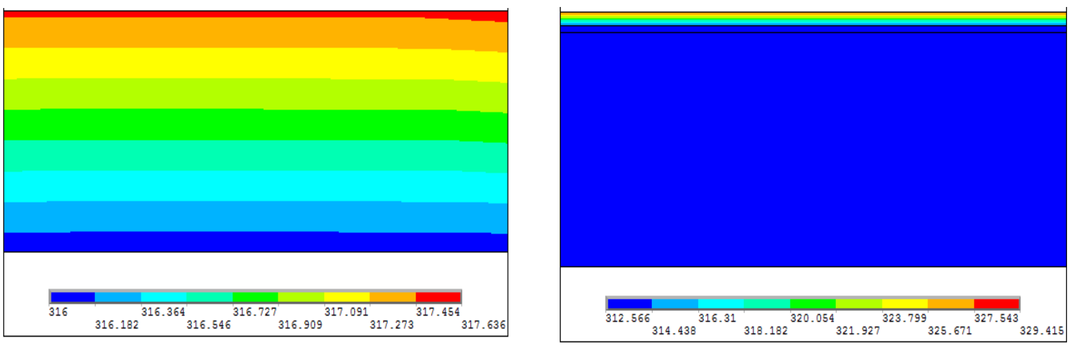


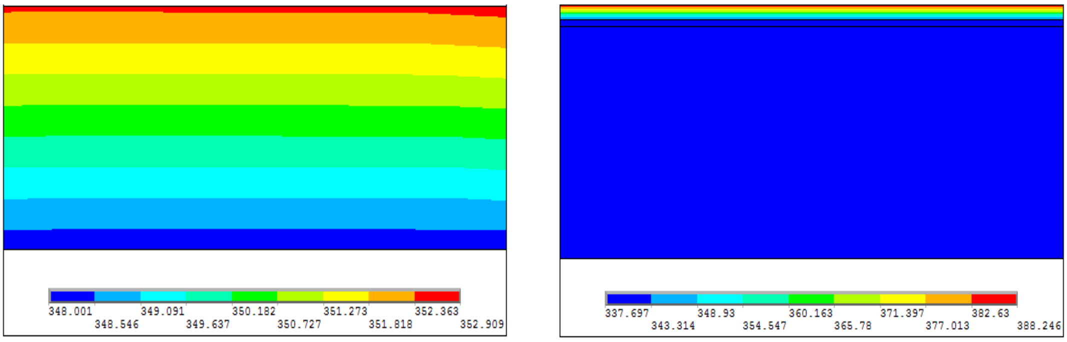
Fig. 3: Percentage increase in top surface temperature for different coating thicknesses after 5s of thermal loading

It has been found that there is about 9.65% increase in top surface temperature by applying 150/150 TBC set up. More thick coating causes further rise in top surface temperature and in case of 1500/150 coating set up, about 46.1% increase is observed in the top surface temperature as compared to the uncoated model.

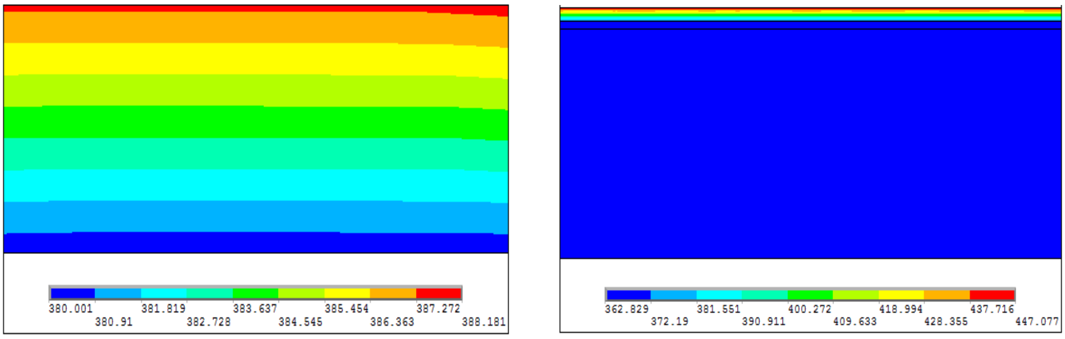
Fig. 4 shows temperature distribution for uncoated and 300/150 coated model after 5 seconds of thermal loading for different operating temperatures from 400 K to 1800 K. The left side figure shows the results for uncoated model while right side model represents coated model results.

(a)

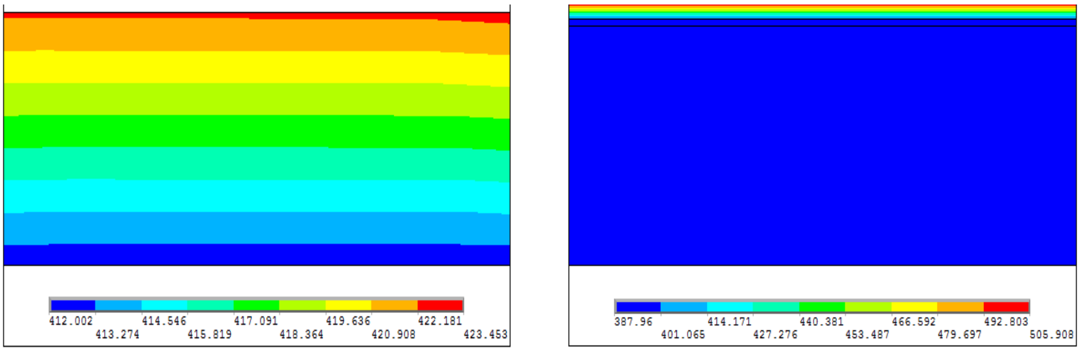



348.001 349.091 350.182 351.273 352.363
348.546 349.637 350.727 351.818 352.909
337.697 348.93 360.163 371.397 382.63
343.314 354.547 365.78 377.013 388.246

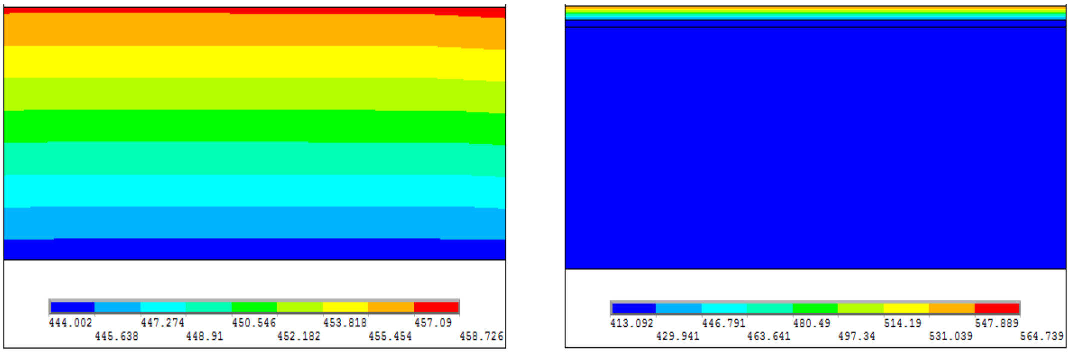
(b)


380.001 381.819 383.637 385.454 387.272
380.91 382.728 384.545 386.363 388.181
362.829 381.551 400.272 418.994 437.716
372.19 390.911 409.633 428.355 447.077

(c)


412.002 414.546 417.091 419.636 422.181
413.274 415.819 418.364 420.908 423.453
387.96 414.171 440.381 466.592 492.803
401.065 427.276 453.487 479.697 505.908

(d)


444.002 447.274 450.546 453.818 457.09
445.638 448.91 452.182 455.454 458.726
413.092 446.791 480.49 514.19 547.889
429.941 463.641 497.34 531.039 564.739

(e)

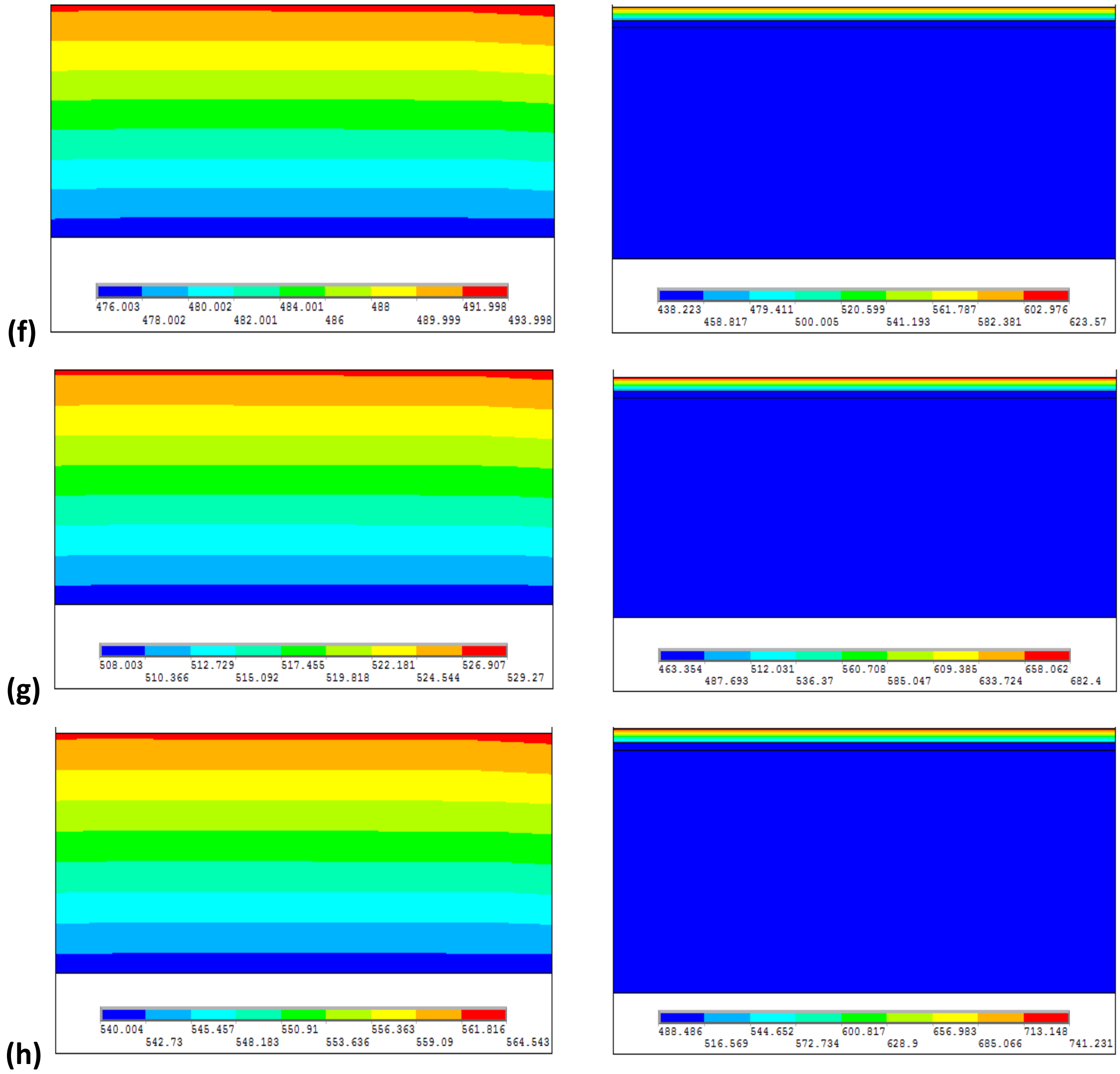


Fig. 4: Simulated temperature distribution along thickness after 5s of thermal loading at different operating temperatures (a) 400 K; (b) 600 K; (c) 800 K; (d) 1000 K; (e) 1200 K; (f) 1400 K; (g) 1600 K; (h) 1800 K ;(left side figure refers to uncoated model while right side figure refers to 300/150 coated model)

The simulation results of Fig. 4 were used to evaluate percentage increase in top surface temperature for 300/150 coated model as compared to uncoated model for varying operating temperatures. The calculated results are plotted in Fig. 5 and show that same coating exhibits about 3.7% increase in top surface temperature at low working temperature of 400 K and the value increases to 31.3% at elevated operating temperature of 1800 K.

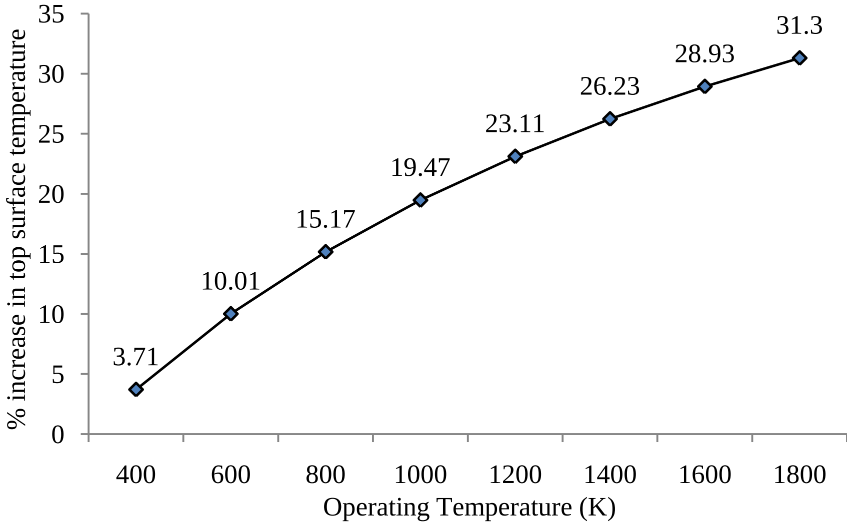


Fig. 5: Percentage increase in top surface temperature with 300/150 coated model for different operating temperatures after 5s of thermal loading

4. CONCLUSION

Finite element methodology based ANSYS simulation was performed to determine thermal behavior of 8Y-PSZ/NiCrAlY thermal barrier coating set up over AlSi alloy material. The coating was found to be highly effective in lowering down the temperatures within the substrate suggesting the appreciable reduction in the heat penetration into the substrate from the hot environment. It was found that for the same thickness of intermediate bond coat layer of NiCrAlY, a thicker Y-PSZ coating was even more effective than a thinner one in terms of heat loss reduction effect. Further, it was observed from the thermal simulation results that the same particular coating thickness behaves in a thermally better and effective manner at elevated operating temperatures and it is worth noting here in this context that the elevated operating temperatures are in fact desirable in the high temperature working devices like IC engines or gas turbines so as to increase thermal efficiency of the system.

REFERENCES

[1] A. K. Saini, Debasish Das and M. K. Pathak, Thermal barrier coatings - applications, stability and longevity aspects. *Procedia Engineering* 38 (2012) 3173-3179.

[2] Ozkan Sarikaya and Erdal Celik, Effects of residual stress on thickness and interlayer of thermal barrier ceramic $MgO-ZrO_2$ coatings on Ni and AlSi substrates using finite element method. *Materials and Design* 23 (2002) 645-650.

[3] Ranjbar-Far, M., Absi, J., Shahidi, S. and Mariaux, G., Impact of the non-homogeneous temperature distribution and the coatings process modeling on the thermal barrier coatings system. *Materials and Design* 32(2) (2011) 728-735.

[4] Buyukkaya, E., Thermal analysis of functionally graded coating AlSi alloy and steel pistons. *Surface & Coatings Technology* 202 (2008) 3856-3865.

[5] Buyukkaya, E. and Cerit, M., Thermal analysis of a ceramic coating diesel engine piston using 3-D finite element method. *Surface & Coatings Technology* 202 (2007) 398-402.