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COMPARISON OF THE THERMAL SHOCK RESISTANCE IN Al_2O_3-SG AND ZrO_2-12%Si+Al COATING SYSTEMS

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ABSTRACT

In this investigation, thermal and structure finite element analysis has been employed to analyse the level of the thermal stresses developed in Al_2O_3-SG and ZrO_2-12%Si+Al coatings subjected to thermal loading. Systems with 0.4mm coating thickness and 4mm substrate material thickness were modelled. Alumina – Ductile Cast Iron coatings with NiAl, NiCrAlY, NiCoCrAlY interlayer were also modelled. Nominal and shear stresses at the critical interface regions (film /interlayer/substrate) were obtained and compared. The results showed that the Al_2O_3-SG coatings has higher thermal shock resistance than ZrO_2-12%Si+Al coating systems. Furthermore, the interlayer thickness and material combinations have a significant influence on the level of the developed thermal stresses. It is also concluded that the finite element technique can be used to optimise the design and the processing of ceramic coatings.

I. INTRODUCTİON

Surface preparation techniques such as plasma spraying, physical vapour deposition and chemical vapour deposition have been used to make convenient material combinations in usage of high technological requirements. High temperature coatings are used for two main functions: either to protect a base metal against corrosion or erosion or to minimise wear. A third function is to reduce the base metal temperature in the case of thermal barrier coatings.

Plasma technique is widely employed for in ceramic coatings. A plasma is a very high energy state and thus transfers heat very fast to the powder, reducing the necessary dwell time at high temperature, which minimizes by the inert nature of the heat source. Plasma spraying is the highly ionised state of mass, consisting of molecules, atoms, ions, electrons and light quantum's. Plasma spraying equipment consists of complex individual apparatuses and devices, for example the plasma torch, power unit, cooling system, powder and gas feeder units. The temperature in the plasma arc centre even attains around 30000K. In this process the powder is melted by temperature taken up by the beam and thrown on the substrate at high velocity. Plasma spraying rarely heats the substrate over 300°C and it is required to keep the substrate temperature using air cooling in the range of 200-250°C. Optimisation of plasma spraying processes has been attempted to decrease coating porosity and achieve better adherence. The deposition efficiency is strongly influenced by both particle size and distribution. Most of the particles must be molten before impingement to produce dense deposits and must have sufficient velocity to splat into the irregularities of the previous splats. Interaction of the molten material with the plasma beam and surrounding atmosphere affects a physical and chemical the transformation of the particles in the plasma beam melt [1].

Plasma coatings are used for many engineering applications in order to improve surface properties of the materials. Perhaps one of the most lucrative applications of ceramic coatings will be for high temperature applications such as gas turbines and diesel engines. Most of those applications are in the form of thermal barrier coatings, which allow for higher engine temperatures and better efficiency [2]. The strength of the bonded system is governed by a number of variables: the thermal and elastic mismatch; the plastic flow stress of the metal; the relative substrate /coating thickness; thickness of interlayer; elasticity and thermal expansion coefficient of interlayer; the fracture resistance of the interface and the flaw distributions in the ceramic and at the interface [3-8]. Most failures in the bond coatings system also depend on processing parameters, i.e. contact temperature, surface composition, solidification of sprayed particles [9].

In the case of thermal loading, it is well known that the thermal stresses are generated at the interface layer when dissimilar materials are bonded together [10]. These stresses cause the debonding and spalling of the coating from the substrate [11-12]. Several means of reducing the

Table 1 Materials Properties

Properties	Al_2O_3	S.G.	12%Si+Al	NiAl	NiCrAlY	NiCoCrAlY
E GPa	340	168	76	103	208	271
ν	0.23	0.31	0.3	0.17	0.17	0.17
α 1/°C .10^{-6}	$8.1x10^{-6}$	$13.7x10^{-6}$	$21.2x10^{-6}$	$14.6x10^{-6}$	$12.7x10^{-6}$	$21.5x10^{-6}$
ρ kg/cm^3	3780	7289	2660	5800	8210	10480
k W/m. °C	24	48.9	150	5.3	95	106
Cp J/kg.°C	1080	418.4	977	593	468	665

thermal stresses level in these systems have been considered, including the application of interlayer and convenient geometry [6]. Therefore interlayer materials were introduced to increase the bonding strength and to reduce the level of the developed stresses.

Finite element numerical analysis has been utilised to study the stresses in a number of problems where material properties differ across an interface, such as in composite, ceramic points, graded ceramic metal materials and coatings [6]. Coatings involve various materials and geometry's, and are generally modelled in two dimensions, thereby calculating stresses both across as along the interface. Most studies of the thermal stresses in coatings have considered steady-state excursions. More recently, the thermal stresses in ceramic-metal bonds have been analysed by taking into account the transient nature of the heat transfer process [13-14].

In this investigation ANSYS finite element packet programme was employed to analyse and to compare the thermal shock resistance of Al_2O_3-SG and ZrO_2-12%Si+Al. Furthermore to obtain the potential of interlayer materials in controlling the level of the thermal stresses in the coating systems. Al_2O_3-SG Coatings with NiAl, NiCrAlY and NiCoCrAlY interface materials were modelled. Furthermore, coatings with different combinations of these interlayer materials were also modelled to evaluate the potential advantage of systems reasonably. The results showed the significant influence of interlayer geometry and material combinations on the level of the developed stresses in coatings subjected to thermal shock.

II. MATERIALS

Table 1 presents, Al_2O_3, 12%Si+Al, NiAl, NiCrAlY, NiCoCrAlY and Ductile Cast Iron (S.G) coating, substrate and interlayer materials data. The thermal expansion coefficient data for the materials are between $8.1x10^{-6}$ - $21.5x10^{-6}$ (/°C), thermal conductivity data are between 24-150 W/m°C and modules of elasticity are between 76-340 GPa.

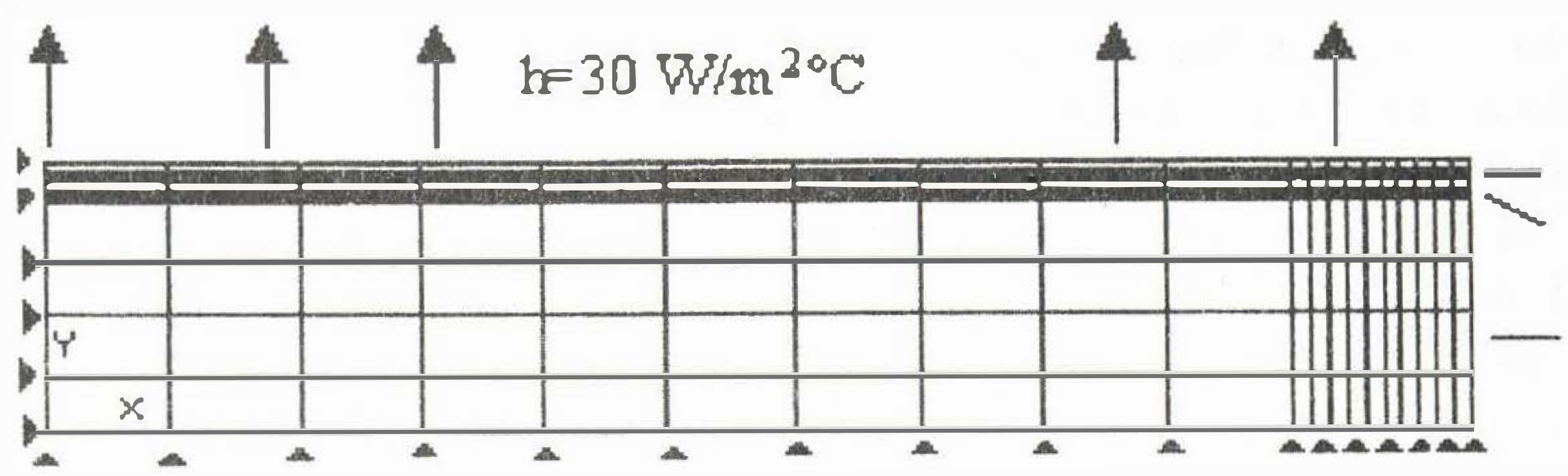

Figure 1. Finite Element Model

III. ANALYSIS

General purpose finite element code ANSYS, is employed to obtain transient thermal/structure coupled solution. The coatings were modelled using 4-node, plane strain, quadratic elements (see, Figure 1). The constraints were imposed on the left and bottom sides of the model and heat transfer was only allowed from the top surface of the model. Thermal loading was applied by cooling down the model from 600 °C to room temperature in very short time using air flow with a 30 W/m^2 °C heat transfer coefficient at the top surface of the model. Al_2O_3-SG and ZrO_2- 12%Si+Al systems with coating / substrate thickness ratio 1/10 were modelled. To study the influence of the coating geometry on the thermal stress levels 1/20 and 1/4 ratios of Al_2O_3-SG were also modelled. Furthermore, three different interlayer materials combinations were also modelled. In those models the combined interlayer thickness were kept 0.4 mm in total. A transient coupled thermal / structure finite element analysis was executed for all coating models. The thermal stresses σ_x, σ_y and τ_{xy} were obtained and analysed.

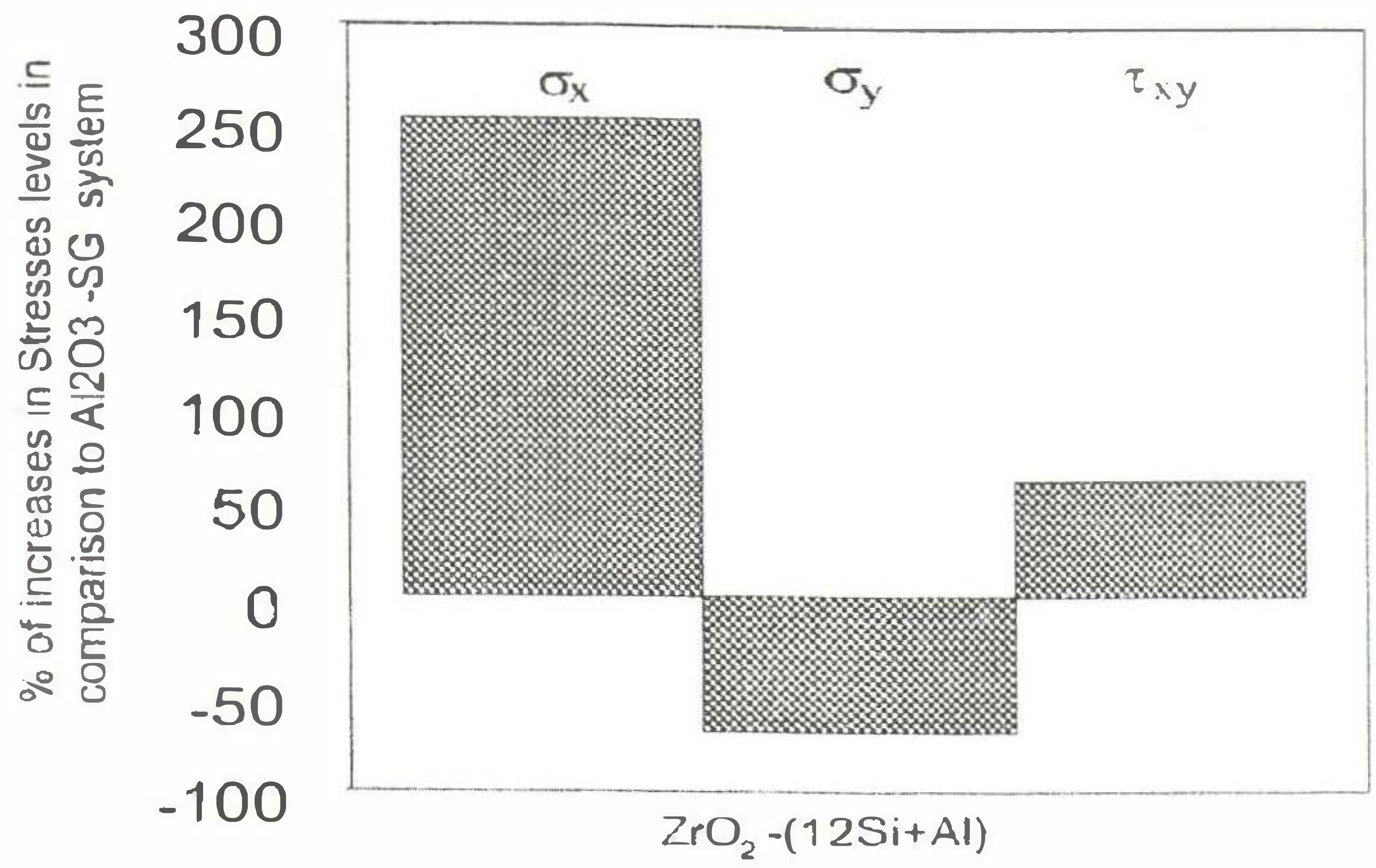

Figure 2: Comparison of the developed thermal stresses in ZrO_2 /12Si+Al) to AL_2O_3-SG system

IV. RESULTS AND DISCUSSIONS

Figure 2 represents the percentage of changes in stresses levels of Al_2O_3-SG system in comparison to the stresses developed in ZrO_2- 12%Si+Al system. It is clear from this figure that there are 250 %, 60% increases in σ_x, and τ_{xy} stresses respectively and a decrease of 70 % in σ_y value. The increase in ZrO_2- 12%Si+Al system stress levels is due to the large mismatch in thermal expansion coefficients of the materials, see Figure 3. This figure presents the variation in stresses with the ratio of the thermal expansions of the materials. There is a linear variation in stress levels with the increase in thermal expansion coefficient ratios.

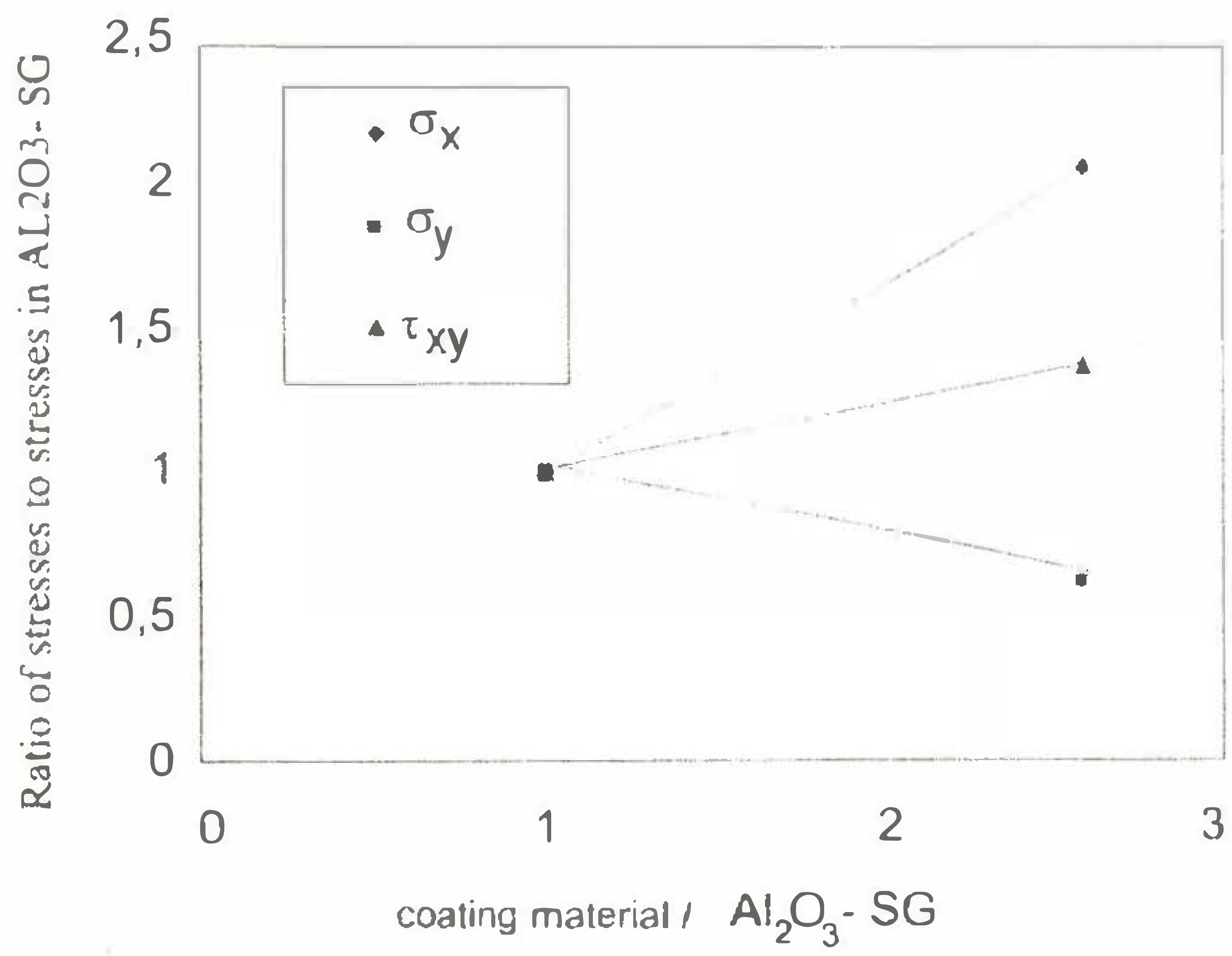

Figure 3. Variation of stress levels with the ratio of coating materials thermal expansion

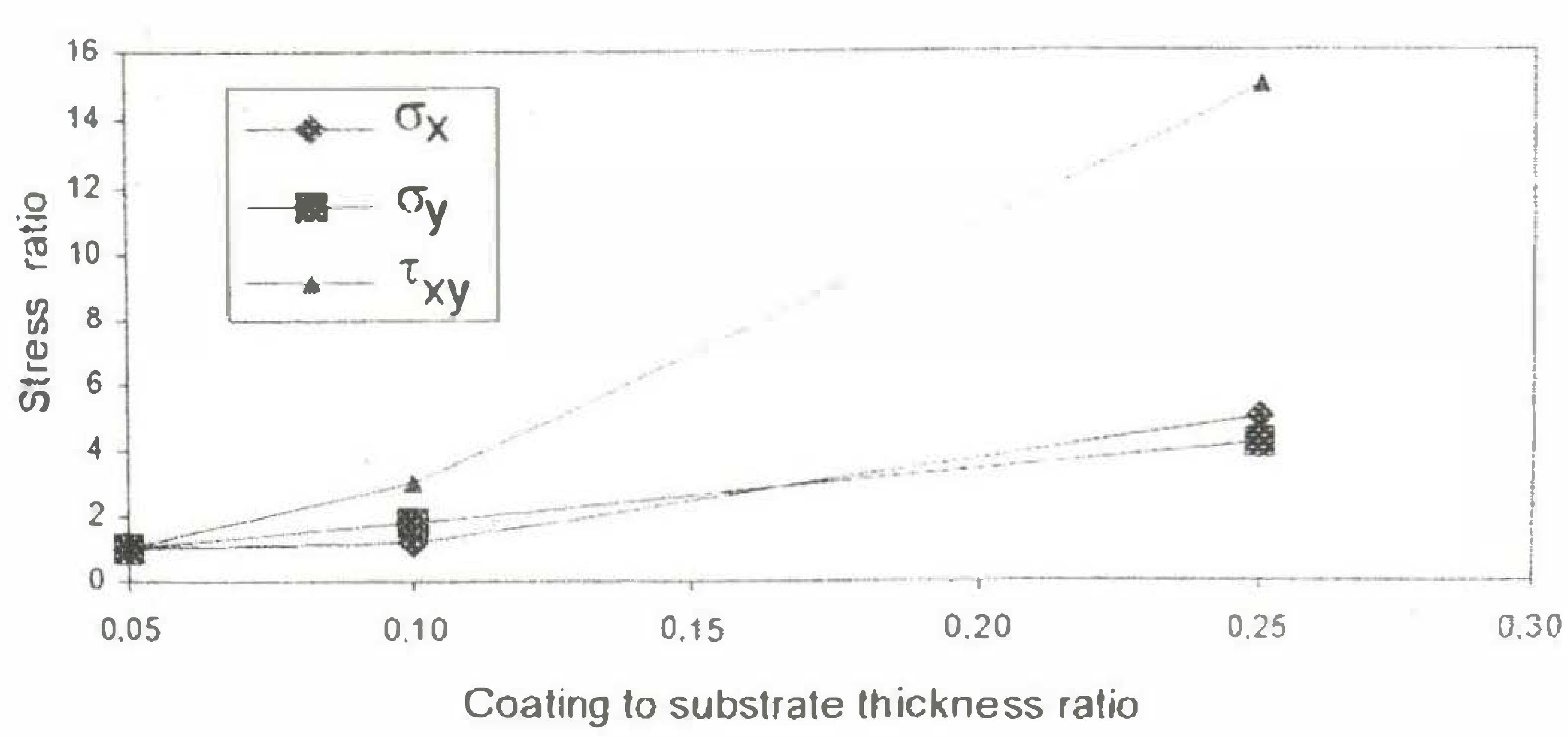

Figure 4. Influence of coating thickness on the developed stresses level for Al_2O_3- SG system

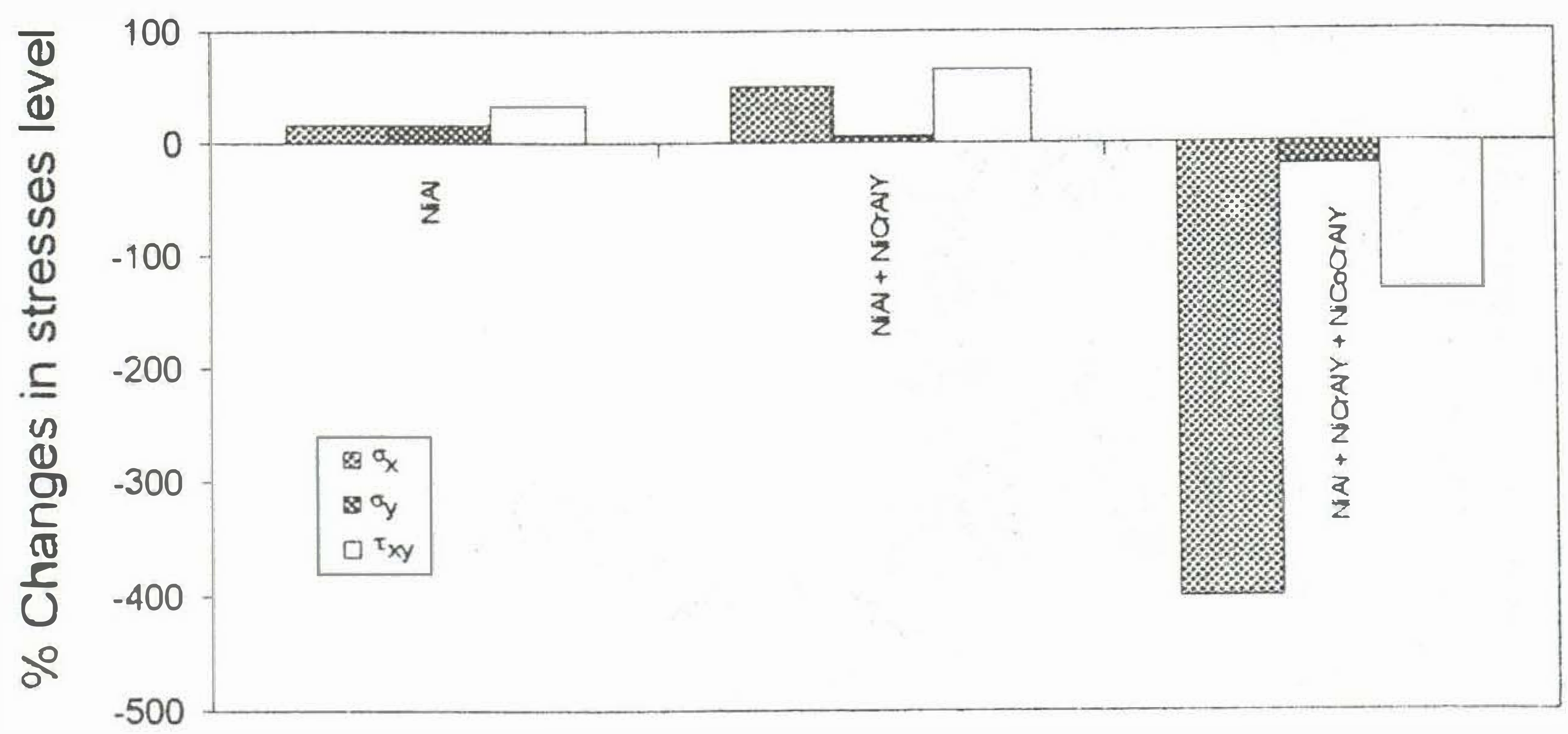

Figure 5. Influence of interlayer material combination on the stresses level

Figure 4 presents the variation in stress levels with coating thickness for Al_2O_3-SG system. The results showed times 15, 5 and 4 increase in σ_x, σ_y and τ_{xy} levels respectively with the increase in coating thickness from 0.2 to 0.8 mm. This is due to the large changes in temperature gradients in thick coating layers.

Figure 5 presents the variation in stress levels with using different interlayer materials. It is clear from this figure that the lowest levels of stresses are in NiAl+ NiCrAlY interlayer systems. The drop in stresses levels are 50%, 66% and 100% for NiCrAlY –NiCoCrAlY, NiAl, NiAl-NiCrAlY, interlayer respectively. We believe that this is resulted from the non -uniformity in temperature distributions because of the large mismatch in some interlayer materials properties.

V. CONCLUSIONS

Under thermal loading conditions, coating, substrate and interlayer materials combinations significantly influence the level of the developed thermal stresses. The thermal shock resistance of Al_2O_3-SG system is higher than that of ZrO_2- 12%Si+Al system. For this system the most convenient interlayer materials combination is NiAl-NiCrAlY. Furthermore the thinner the coating the lower are the levels of the developed stresses. It is also concluded that the Finite Element Technique can be used to optimise the design and the processing of ceramic coatings.

VI. REFERENCES

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