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# Impact Temperature in Splat and Splat-Substrate Interface in HVOF Thermal Spraying

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***Abstract*—**An explicit axisymmetrical FE methodology is developed here to study the particle temperature arising in WC-Co particle on an AISI 1045 steel substrate. Parameters of constitutive Johnson-cook model were used for simulation. The results show that particle velocity and kinetic energy have important role in temperature arising of particles.

***Keywords*—**FEM, HVOF, Interfacial Temperature, Splat

## I. INTRODUCTION

HVOF Thermal spray technology has been proposed as an alternative to hard chromium plating showing in some applications promising results [1].

For example, one requirement for tungsten carbide coatings is to have better wear and fatigue properties than hard chromium when applied in aircraft manufacturing [2], [3]. Thermal spraying with high velocity oxygen fuel has been very successful in spraying wear resistant WC–Co coatings with higher density, superior bond strengths and less decarburization than many other thermal spray processes. This is attributed mainly to its high particle impact velocities and relatively low peak particle temperatures.

The finite element method is widely used for the evaluation of mechanical property of machine elements such as residual stress and failure mechanism such as delaminating, fatigue behavior and Stress Intensity Factors for various types of crack configurations [1].

In the present work, the development of an axisymmetrical finite element model is presented to simulate the plastic deformation behavior in an HVOF sprayed particle. As such, the model can be used across a range of impact velocities and particle temperatures. WC-Co powders are selected for this purpose. The WC-Co composite particle is considered as a single entity, with a single set of physical properties.

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## II. EXPERIMENTAL PROCEDURE

The current work describes the development of an FE methodology to simulate the temperature of splat and splat-substrate after impact in HVOF sprayed coatings. For this purpose a two dimensional axisymmetric model of WC-12Co particle impacting on an AISI 1045 substrate disc was generated using ABAQUS version 6.10.

## III. RESULTS AND DISCUSSION

Impact of sprayed particles can also be treated as a high-temperature shot peening process. The impact of thermally sprayed particles onto a substrate is a non-linear dynamic contact phenomenon. The microscopic and macroscopic response of the impacting particle and the underlying substrate under such loading conditions is strongly affected by the strain, strain rate, temperature and microstructure of the material [4]. Using an appropriate constitutive equation defining the material properties is therefore essential for modeling such processes. The constitutive relation proposed by Johnson and Cook (the J–C model) is widely used in numerical models involving high strain rates and temperatures and its use is generally limited to the impact of solids. The J–C model is stated as follows [5]:

$$\bar{\sigma} = [A + B(\bar{\varepsilon}^{pl})^n][1 + C\ln(\frac{\dot{\bar{\varepsilon}}^{pl}}{\dot{\varepsilon}_0})](1 - \hat{T}^m) \tag{1}$$

Where $\bar{\varepsilon}^{pl}$ is the equivalent plastic strain, $\dot{\bar{\varepsilon}}^{pl}$ is the equivalent plastic strain rate, and A, B, C, m and n are material parameters and $\dot{\varepsilon}_0$ is the reference strain rate. $\hat{T}$ is a non-dimensional temperature, $T_r$ room temperature and $T_m$ is melting temperature.

$$\hat{T} = \frac{T - T_r}{T_m - T_r} \tag{2}$$

$$T = T_r + \frac{\beta}{\rho c_p}\int \bar{\sigma} d\bar{\varepsilon}_p \tag{3}$$

Where β is the work to heat conversion factor, $c_p$ is the heat capacity and ρ is the density.

During impact, much of the kinetic energy of the particle will be transformed into heat. Hutchings [6] argued that, during impact of a particle with a metal target during an erosion process, more than 80% of the original kinetic energy of the particle was transformed into heat, with the rest of the energy being accounted for by the stored energy of plastic deformation, the elastic wave energy and the rebound kinetic energy.

In a more recent study of cold-spray deposition, it was assumed that 90% of the kinetic energy of the particle was dissipated into heat [7].

Parameters of J-C model of AISI1045 substrate is shown in table1 [8]. The Johnson-cook model parameters of coatings are from Ref. [5]. Thermophysical properties of WC-Co cermet is shown in table II [6].

TABLE I
J-C PARAMETERS OF SUBSTRATE [5]-[6]

| parameters (J-C) | WC-Co | AISI1045 |
|---|---|---|
| A (MPa) | 1550 | 553.1 |
| B(MPa) | 22000 | 600.8 |
| N | 0.45 | 0.234 |
| C | 0.016 | 0.013 |
| M | 1 | 1 |
| Melting temp. K | 1768 | 1356 |
| Reference strain rate (1/s) | 1 | 1 |

A two-dimensional axisymmetric model of a 30 μm diameter WC-Co particle impacting on an AISI 1045 substrate disc of 1mm radius and 1 mm thickness was generated using ABAQUS version 6.10. A dynamic, explicit temperature–displacement coupled analysis was carried out to study the high strain-rate impact process using ABAQUS/Explicit. In the model, spray conditions were characterized by the particle velocity and temperature. These parameters were considered as the key variables in the FE model and analysis were performed in different velocities.

Four-node linear displacement and temperature elements were used to discretize the particle and the substrate. All the displacements on the bottom face of the substrate were restrained. Symmetry boundary conditions were used on the left-hand side of the model. Upon impact, the sprayed particle deforms and spreads over the substrate, forming a splat. The FE analysis assumes that, after first contact, the particle remains attached to the substrate. This was implemented by assigning a no-separation criterion between the contacting nodes of the impinging particle and the underlying substrate. Fig. 2 illustrates the axisymmetric FE model of an splat

In this work, it was assumed that 90% of the inelastic energy generated during impact was dissipated as heat. At the substrate-splat interface significant temperature increase is observed as a result of kinetic energy being converted to internal energy and part of it to plastic deformation. Fig. 1 describes the predicted temperature distribution across the splat and the substrate thickness 100 ns after initial contact. An increase of approximately 130 K is predicted in the particle upon impact in 375m/s. The impact process also imposes extra heat to the substrate, and is predicted to affect a region up to about 40 μm deep.

A greater temperature rise is predicted in the substrate along the particle–substrate interface when particles are sprayed at 425 m/s. In this region, the temperature rises to 1345 K at 100 ns.

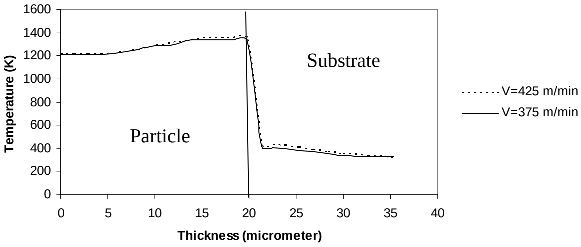


Fig. 1 FE-predicted temperature distribution across the splat and the substrate thickness after the impact (T=1260 K)

The temperature contours from sprayed splats having a temperature of 1200K, landing at 425m/s is presented in Fig. 1 for impact time of 100 ns. The temperature contours on the substrate surface indicate that the temperature increase in substrate is much lower than that of the particle, which is attributed to the smaller plastic deformation experienced by the substrate during impact.

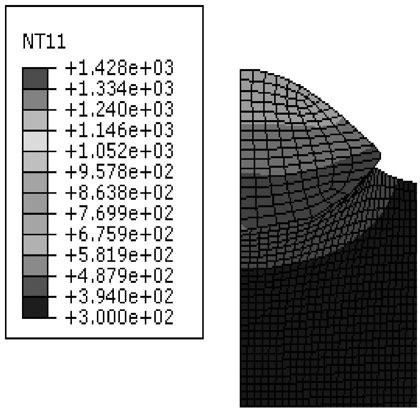


Fig. 1 Temperature contours on the splat and substrate 100 ns after impact

## IV. CONCLUSION

A two-dimensional axisymmetric model of a 30 μ diameter WC-Co particle impacting on an AISI 1045 substrate was developed. The impact velocity has important role in temperature arising in splat and splat-substrate interface.

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