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Development Trend in Investigation of Residual Stresses in WC-Co Coating by HVOF Thermal Spraying

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***Abstract*—**In this paper, the techniques for estimating the residual stress in high velocity oxy fuel thermal spray coatings have been discussed and compared. The development trend and the last investigation have been studied. It is seemed that the there is not effective study on the effect of the peening action in HVOF analytically and numerically.

***Keywords*—**HVOF, WC-Co, Residual stress, Compressive stress

I. INTRODUCTION

OVER the last years, the substitution of hard chromium plating has been promoted due to the new legislation concerned to hazardous wastes of Galvanic Industries. Thermal spray technology has been proposed as an alternative to hard chromium plating showing in some applications promising results. For instance, one requirement for tungsten carbide coatings is to have better wear and fatigue properties than hard chromium when applied in aircraft manufacturing [1], [2]. Thermal spraying with high velocity oxygen fuel (HVOF) 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 [3]. As a class of hard composite materials of great technological importance, WC–Co powder cemented carbides are widely used by various thermal spray processes to deposit protective coatings in a large variety of applications such as power plants, oil drilling, turning, cutting and milling, where abrasion, erosion and other forms of wear exist [4]. Less attention has been given to develop thick coatings for repair applications, which is significant interest for the aerospace industry. In this paper we have a review in studies that have been made by researchers in the last years.

II. RESIDUAL STRESSE

The thermal spray coating process imparts a residual stress in the layer surface of the coated component.

The residual stress state that develops in a deposit depends largely on the thermal conditions to which the system has been subjected, and is a combination of quenching stresses that arise during deposition and cooling stresses post-deposition(Fig 1) (a , b). There are two main origins of residual stresses in thermal spray coating systems. The first source is due to the fast cooling to which the spray particles are subjected, i.e. a cooling process that begins from the melting temperature and drops to the temperature reached by the substrate during the deposition process (primary cooling). These stresses are called ‘intrinsic’, ‘deposition’ or ‘quenching’ stresses and are always of a tensile nature. The second source is caused by the difference in the thermal expansion coefficients between the coating (αc) and substrate (αs), which leads to residual stresses induced by the mismatch of thermal shrinkage during cooling from the process temperature (average temperature reached by the coating-substrate system after deposition) to room temperature, during the so called secondary cooling. Depending on the sign of this difference and the deposition temperature, the evolution of ‘thermal stresses’ could be in tensile or compressive nature. Fig.2 shows the Factors influencing the generation of residual stress in thermal spray coatings. The Final residual stress through the whole coating/substrate system is determined by superposition of stresses of different nature induced during the spray process: quenching, thermal mismatch, and Peening stress, Together with the compressive stress state of the substrate induced during the grit blasting prior to spraying (Fig.3). One challenge in HVOF thermal spray is to control the residual stresses through the deposit thickness when a coating to be sprayed is several millimeters thick, and to understand the relationship between these stresses and coating adhesion. The adhesion strength of a coating is depends on the bonding between the coating and substrate as well as on the coating microstructure. Both the bonding and the microstructure are strongly influenced by residual stress distribution. It is commonly known that the level of residual stresses can significantly change at the coating substrate interface creating delaminations, which in worst cases can cause spallation. Compressive residual stresses at the interface are known to inhibit the formation of through thickness cracks and to improve adhesion bonding and fatigue strength [5], [6].

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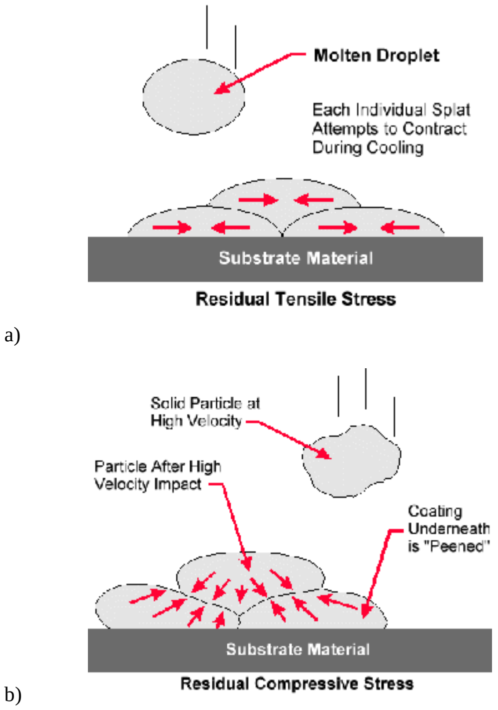

Fig.1 Mechanism of residual stress generation during the impact

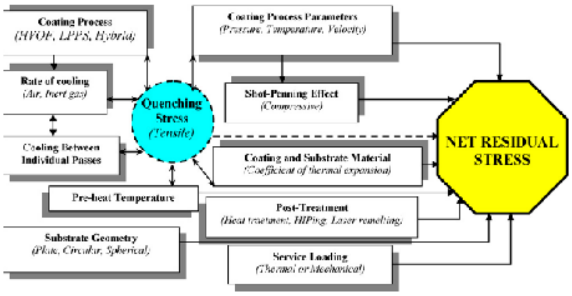

Fig. 2 Factors influencing the generation of residual stress in thermal spraying

III. RESIDUAL STRESS MEASURMENT TECHNIQUES

A number of techniques have been used in the past decades to measure residual stresses in thermal spray coatings. Curvature measurement method relay on the monitoring of changes in component distortion, either during deposition or after. (Fig4)

The modified Layer Removal Methods use material removing to allow relaxation of the stresses. Layers are removed by polishing one side of specimen, then the stresses become unbalanced and the specimen bends. (Fig 5).Diffraction methods (X-Ray and Neutron) are based on the elastic deformation within polycrystalline material to measure internal stresses in a material. The stresses cause deformation i.e, change in the distance between the lattices, which are used as internal strain gages. Shift in diffraction peaks are recorded from which the strain distribution is calculated (Fig 6) (a, b).Compared to low energy X-rays the main advantage of working with neutrons is the Possibility to analyze greater depths, i.e., higher coating thickness [7].

The through-thickness stress field is also determinable. By means of the incremental hole drilling method the tests conduct by carrying out successive drilling steps in depth until the substrate be reached.

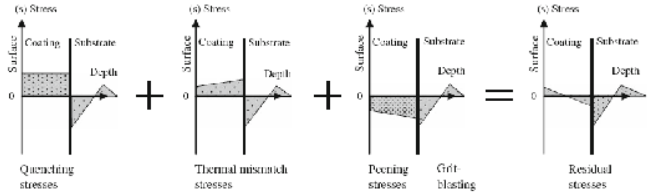

Fig. 3 Schematic representation of radial residual stress distribution in HVOF sprayed coating/substrate system[7]

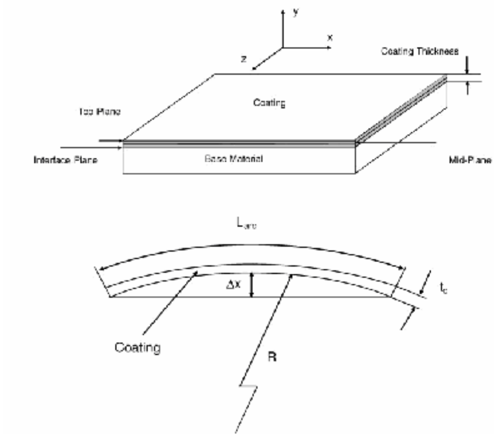

Fig.4 curvature method in residual stress estimation[8]

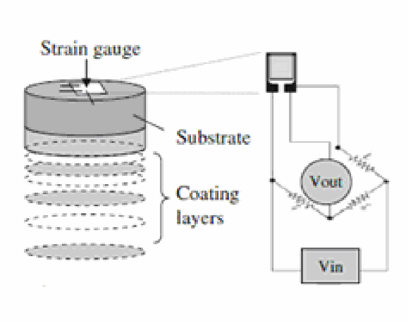

Fig. 5 layer removal method in residual stress estimation [7]

Fig. 7(a,b) shows a schematic representation of radial residual stress distribution in HVOF sprayed coating/substrate system relaxation strain/depth curves (by rossett strain gages) from which it is possible to calculate the through-thickness residual stress variation, provided that correct values for the calibration coefficients were determined by means of the integral method. Fig. 8 shows the diagram of residual stress measurement steps of hole drilling method.

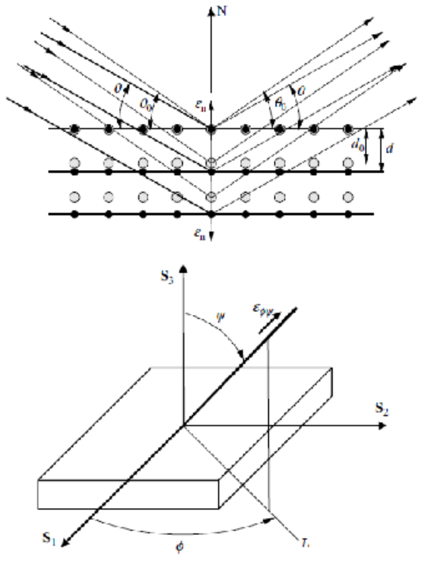

Fig. 6 residual stress estimation by XRD

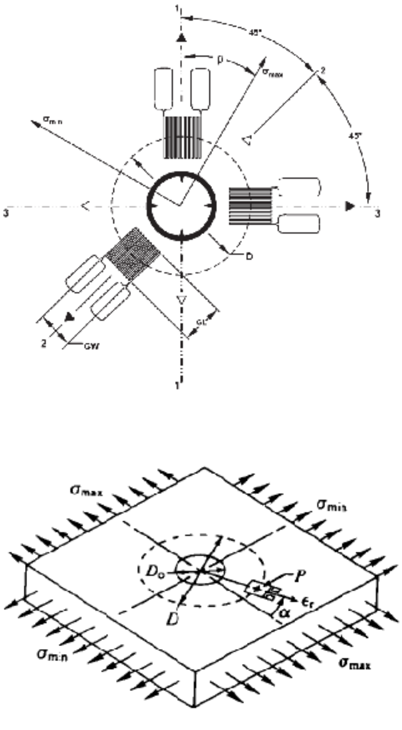

Fig. 7 residual stress estimation by hole drilling method

IV. RECENT RESEARCHES

Determination of residual stresses in thermal spray processes is An important technological aim since the residual stress levels Present in the coatings and their sign have a significant effect on coating performance. Y.C. Tsui and T.W. Clyne in 1997 introduced an analytical model for prediction residual stress in progressively deposited coatings in planar and cylindrical geometry. Their model was based on concept of misfit strain, caused by either the deposition stress or by differential thermal contraction between substrate and coating during cooling [10].

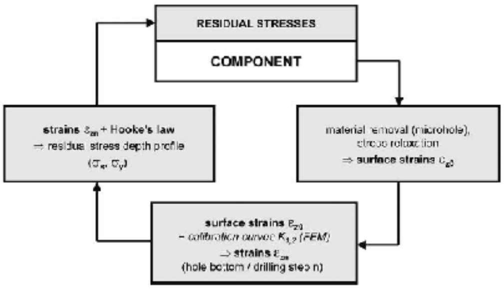

Fig 8 Diagram of residual stress measurement steps of hole drilling method[9]

From 1997 till know Tsui-Clyne model is used to estimate the residual stress from knowledge of deposition temperature, material properties and specimen dimensions. In year 2002, J.M Miguel et al, had a study on WC-Co Thermally Sprayed Coatings. In order to determine the optimum Spraying Conditions with respect to the residual Stress level Present, the acoustic emission (AE) during four points bend test on WC-Co sprayed onto mild steel substrate was investigated [11]. The Residual stress in HVOF thermally spray thick deposits has been studied by J.stokes and looney in year 2003. They tried to study the residual stress analytically, but they did not discuss the effect of peening during the impact process in high velocities. A change of deposit stress-state from Tensile to compressive stress with deposit thickness is analyzed in Term of quenching and cooling stresses. In year 2005, R. Ghafouri Azar et al. developed a modeling of residual stresses in thermal spray coatings. They reported that high stresses are present in at the interface between the coating and substrate they emphasized that the magnitude of stresses increases significantly with coating thickness. Such stresses are relieved by voids such as pores or cracks in coatings. Residual stresses increase with coating Temperature and can be decreased by preheating the substrate. In year 2008, Y.Y Santana has a study on characterization and residual stresses of WC-Co thermally sprayed coatings, he use a steel substrate and WC-12Co coating, in two different thickness by means of two different methods. Firstly XRD technique to determine the surface residual stress of coating by means of method called "Sin$^2\varphi$" method. Secondly an incremental hole drilling technique together with the integral method, which allowed that analysis of non uniform through thickness residual stress, it has been determined that the surface residual stresses have compressive Nature, which could be due to the grinding process. The result of hole drilling test indicated that the through thickness residual stress distribution are not uniform and are characterized by the presence of tensile stresses. Such stresses were observed to decrease toward the coating-substrate interface where the compressive component of the stress state becomes greater that the tensile component [9]., in year 2008. It is found that existing of WC modifies temperature rise and the temperature gradient in the coating, In which case, increasing WC content reduces the temperature gradient. The young's modulus, the magnitude of the residual stress, and the fracture toughness of the coating increase with increasing WC content in coating [12].Estimation of residual stress, and its effects on the mechanical properties of D-gun sprayed WC-Co coating was done by Tie-gang Wang et al. in year 2009. The analysis results emphasized the significance of peening stress in controlling the final stress state of the coated specimen due to high velocity and kinetic Energy during the D-gun spraying process. They mentioned that the effects of residual stress on the mechanical properties of the coating namely compressive residual stress could significantly; improve the coating properties, where the tensile stress impaired the coating property [13].

V. CONCLUSION

The comparison of several techniques in estimation of residual stress in high velocity Oxy fuel has been studied. A summery of conclusions is as follow:

- The various methods could be used to estimate the residual stress in WC-Co Coating. The curvature method for sheet substrate and XRD for surface to 4 microns beneath the top layer as well as the hole drilling method for through thickness measurement.
- The low penetration value of X-ray in WC-Co has been limited the application of this method to estimate the through thickness residual stress.
- The curvature method that is used in Tsui- Clyne model uses the final curvature and don’t consider the peening action separately.
- It is proposed that some study may be done to simulate the peening action of inflight WC particle during the impact to substrate.

REFERENCES

[1] U. Erning, M. Nestler, Proceedings of United Thermal Spray Conference (UTSC 99). Düsseldorf, March 1999, p. 462.
[2] T. Sahraoui, S. Guessasma, N.E. Fenineche, G. Montavon, C. Coddet,Materials Letters 58 (2004) 654.
[3] Y. Qiao, Y.R. Liu, T.E. Fischer, Sliding and abrasive wear resistance of thermalsprayed WC–Co coatings, Journal of Thermal Spray Technology 10 (2001) 118– 125.
[4] T. Sahraoui, S. Guessasma, N.E. Fenineche, G. Montavon, C. Coddet, Materials Letters 58 (2004) 654–660.
[5] R.J.K. Wood, B.G. Mellor, M.L. Binfield, Wear 211 (1997) 70–83.
[6] T.W. Clyne and S.C. Gill, Residual Stresses in Thermal Spray Coatings and Their Effect on Interfacial Adhesion: a Review of Recent Work, J. Therm. Spray Tech., 1996, 4, p 401-409.
[7] C. Lyphout, Residual Stresses Distribution through Thick HVOF Sprayed Inconel 718 Coatings, Journal of Thermal Spray Technology, Volume 17(5-6) Mid-December 2008—915.
[8] B.S. Yilbas, A.F.M. Arif, Residual stress analysis for hvof diamalloy 1005 coating on Ti–6Al–4V alloy, Journal of Surface and Coatings Technology, Volume 202, Issue 3, 5 December 2007, Pages 559-568
[9] Y.Y. Santana, J.G. La Barbera-Sosa M.H. Staia, J. Lesage, E.S. Puchi-Cabrera, D. Chicot and E. Bemporad, Measurement of residual stress in thermal spray coatings by the incremental hole drilling method, Journal of Surface and Coatings Technology,Volume 201, Issue 5, 25 October 2006, Pages 2092-2098
[10] Y.C Tsui, T.W. Clyne, Journal of Thin Solid Film 306(1997)34-51.
[11] Miguel, J.M., Guilemany, J.M., Mellor, B.G. and Xu, Y.M. (2003) Acoustic emission study on WC-Co thermal sprayed coatings. Materials Science and Engineering A, 352, (1-2), 55-63
[12] Z.Y. Taha-al, M.S. Hashmi, and B.S. Yilbas, Effect of WC on the residual stress in the laser treated HVOF coating, Journal of Materials Processing Technology Volume 209, Issue 7, 1 April 2009, Pages 3172-3181
[13] Tie-Gang Wang, Sheng-Sheng Zhao, Wei-Gang Hua, Jia-Bao Li, Jun Gong, Estimation of residual stress and its effects on the mechanical properties of detonation gun sprayed WC–Co coatings, Journal of Materials Science and Engineering: A , Volume 527, Issue 3, 15 January 2010, Pages 454-461