Determination of residual stress in coated surfaces [1]

Peter Weidmann[1, a *], Giancarlo Pedrini[2, b], Venancio Martínez-García[3, c], Martin Wenzelburger[3], Andreas Killinger[3], Siegfried Schmauder[1], Rainer Gadow[3], Wolfgang Osten[2]

[1]University of Stuttgart, IMWF, Pfaffenwaldring 32, 70569 Stuttgart, Germany

[2]University of Stuttgart, ITO, Pfaffenwaldring 9, 70569 Stuttgart, Germany

[3]University of Stuttgart, IFKB, Allmandring 7b, 70569 Stuttgart, Germany

[a]peter.weidmann@imwf.uni-stuttgart.de, [b]giancarlo.pedrini@ito.uni-stuttgart.de, [c]venancio.martinez@gsame.uni-stuttgart.de

Introduction

The reduction of manufacturing costs and enhancement of product lifetime are central goals for many modern research areas. Especially components which are supposed to withstand aggressive thermal, mechanical or chemical environments can be challenging in their production and maintenance. A reliable way to protect metals from high thermal and abrasive loads, i.e. turbine blades, can be achieved by coating them with suitable ceramics by atmospheric plasma spraying (APS). Hereby, a ceramic powder is injected into a plasma jet, molten and accelerated towards the specimen. During the impact of the liquid particle it is highly deformed and will quench almost immediately due to the comparably low heat capacity which leads to high tensile stresses in the solidified ceramic. When the coating is finished the whole component will bear a non-homogeneous temperature distribution, but even for a uniform temperature the differences in thermal expansion coefficients of substrate and coating will lead to further residual stresses during the cooling-down. While this residual stress cannot be avoided, it is possible to conduct the process in such ways, that a sometimes even beneficial state can be achieved, i.e. a compressive residual stress within the brittle coating. Nevertheless it is of great importance to know the existing stress state of the investigated part in order to ensure high quality products. A profound determination technique for this case is the incremental hole drilling (IHD). Hereby, a mechanical drill removes incrementally material out of the stress afflicted component. As a new equilibrium is achieved, the area around the hole deforms. This deformation is mostly measured by a strain gauge and with a proper case sensitive calibration the underlying residual stress can be derived from it [2], [3].

The drawbacks of this method are the necessity of mechanical contact with the specimen, the specimen preparation with strain gauges and the overall time-consuming drilling operating. Therefore, a new approach shall be investigated, where the material removal is conducted via laser ablation and the occurring surface displacements will be measured by digital holography (DH).

Conclusions and outlook

First results proof the applicability of laser ablation to relax residual stress, where the resulting surface displacements are measured by digital holography and evaluated according to the integral method. The laser ablation seems to imply only neglectable amounts of heat, while the resulting hole geometry can be approximated by simple geometrical forms and, therefore, calibration values can be obtained numerically. A spot focused laser beam leads to some variations in the holes geometry, but overall axial symmetrical removals can be evaluated by using the approach of [4], [5], even if not ideal cylindrical holes and inhomogeneous specimen are present. Hereby, the results of residual stress profiles show the same qualitative behaviour as IHD determinations, but tend to a higher deviation. The main reason is related to uncertainties of the ablated hole structure.

By using SLM to ablate material in notch-form (Figure 1), the structure of removal is significantly more reliable regarding its dimensions. The extensive displacement measurements can be evaluated with a special integral method based scheme and data dependent weighting functions to reduce the corresponding deviation considerably. Hence, especially surface near stresses could be determined more accurate compared to classical IHD determinations. Now continuing analyses should be performed in order to validate the results further.

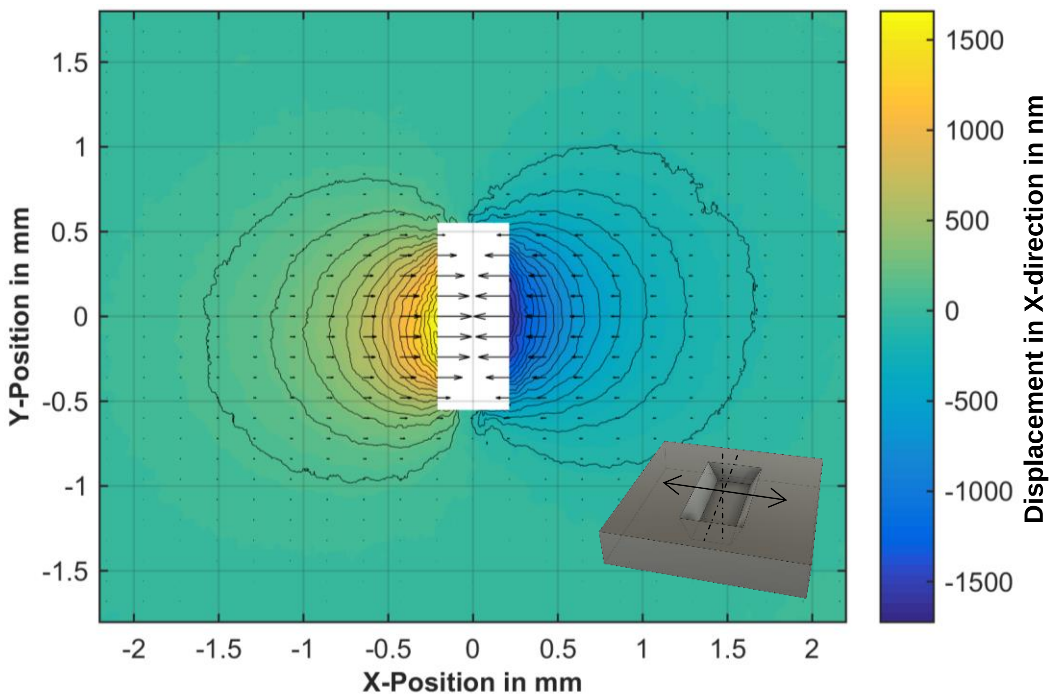

Figure 1: Displacment field around SLM albated notch in residual stress afflicted material

Acknowledgement:

This work was supported by the German Research Foundation (DFG) under Grant Nos. GA746/10, OS111/37 and SCHM746/120.

References

[1] P. Weidmann, G. Pedrini, V. Martínez-García, M. Wenzelburger, A. Killinger, S. Schmauder, R. Gadow, and W. Osten, "Evaluation of Residual Stress Determinations Conducted with Laser Ablation and Optical Displacement Measurement", *Materials Research Proceeding*, vol. 2, pp. 323–328, 2016.

[2] P. Weidmann, U. Weber, S. Schmauder, and V. Martinez Garcia, "Investigation of Influence Factors on Residual Stress Determination within Coated Surfaces in Consideration of the Differential and Integral Method", *Advanced Materials Research*, vol. 996, pp. 307–312, 2014.

[3] M. Wenzelburger, D. Lopez, and R. Gadow, "Methods and application of residual stress analysis on thermally sprayed coatings and layer composites", *Surface and Coatings Technology*, vol. 201, no. 5, pp. 1995–2001, 2006.

[4] G. Schajer and T. Rickert, "Incremental Computation Technique for Residual Stress Calculations Using the Integral Method", *Experimental Mechanics*, vol. 51, pp. 1217–1222, 2011.

[5] G. S. Schajer and M. Steinzig, "Full-field calculation of hole drilling residual stresses from electronic speckle pattern interferometry data", *Experimental Mechanics*, vol. 45, no. 6, pp. 526–532, 2005.