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Application of thermography in cyclic load and thermal shock testing of steel components with ceramic coatings deposited by cascaded plasma torch

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ABSTRACT

- **Behaviour of ceramic coatings deposited on steel substrate was tested by cyclic loading and thermal shock. Both tests of ceramic coatings were observed with thermographic camera TIM400. Three different ceramics: Al2O3, Cr2O3 and Cr2O3-5SiO2-3TiO2 were deposited by plasma cascade torch SinplexPro. Relation between temperature and stress and reactions to thermal shocks were inspected. Frequency of 10 Hz, step of 20 MPa and stress ratio R0,1 were used for cyclic load testing. Load was increased every 10 minutes until the specimen fractured. The influence of diverse ceramic coatings on fatigue limit is determined. Thermal shock temperatures were selected based on properties of coating material. To reach desired temperature, resistance heating was used and afterwards compressed air cooled the specimens.**

INTRODUCTION

- Plasma deposition technology is the only thermal spraying technology to deposit high quality oxidic ceramic coatings. Using plasma torch offers high enough temperatures and fast flow for ceramic deposition. High temperature is crucial in deposition of ceramic materials and creating quality coating, because of its high melting temperatures. It is desirable for powder particles to flatten on the surface. Flow or solid particles that do not flatten cause porosity and defects in coatings. Oxidic ceramic coatings are often used as wear protection and corrosion protection. This paper focuses on coating behaviour while undergoing cyclic load testing and thermal shock testing. Thermal shock can occur by fast cooling of heated sample. Samples are cooled by cold water or compressed air. It is also possible to execute reversed thermal shock by rapid heating of cold sample.
- Three oxidic ceramics were chosen as coating materials. Aluminum oxide Al2O3 has high hardness, good wear resistance and is stable in high temperatures. Alumina itself should withstand temperatures up to 1650 °C. Chromium (III) oxide Cr2O3 also provides good wear resistance and heat stability. On top of that are chromia coatings chemically stable. The third chosen material is Cr2O3-5SiO2-3TiO2 with similar properties as alumina and chromia. Chromia and Cr2O3-5SiO2-3TiO2 can be used in service temperatures up to 540 °C. Using thermography and cyclic loading is an innovative alternative to the standard method of fatigue limit evaluation. Infrared thermography is based on detecting radiation emitted by objects. If the observed object change temperature, the amount of emitted radiation also changes. During cyclic loading can be this change observed and evaluated.

EXPERIMENTAL PROGRAM

As a testing specimen were created flat bars cut out by water jet (Figure 1) with ceramic coating on both sides. Yellow color is marking the placement of ceramic coating on both sides. Thermal field was observed with thermographic camera during both experiments.

- Cyclic load testing: samples were cyclically loaded with frequency of 10 Hz and stress of 20 MPa. The stress ratio of the experiment was R0,1. Every 10 minutes the load increased by 20 MPa to see how ceramic coatings withstands cyclic tensile straining and to determine fatigue strength.
- Thermal shock testing was executed by fast cooling of heated specimen. In this study compressed air was used as a cooling medium. Samples were heated with direct high-frequency resistance heating system. For the purpose of this experiment a heating rate of 10 °C/sec, holding time – 60sec and cooling rate of 10 °C/sec were used and 100 cycles were planned. There was direct heating of the substrate and cooling was performed from both sides directly and symmetrically on the ceramic

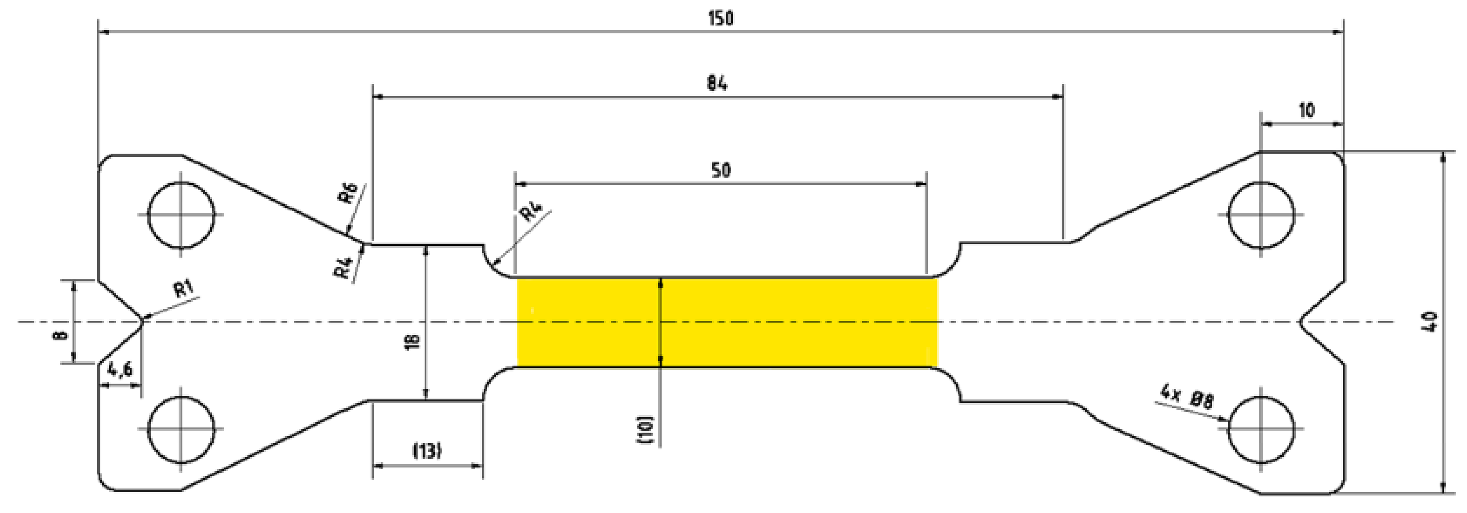

Figure 1. Testing specimen

RESULTS AND DISCUSSION

During cyclic load testing Al2O3 and Cr2O3-5SiO2-3TiO2 coatings started to separate between 280 MPa and 300 Mpa. Cracks in Cr2O3 started do initiate at slightly higher stresses. For every coating material were performed four measurements to find fatigue strength (Table 1).

Table 1. Summary of cyclic load testing and fatigue strength

Substrate	Coating material	Temperature	Stress ratio	Fatigue strength [MPa]
S235JR	Al2O3 Cr2O3 Cr2O3-5SiO2-3TiO2	Room temperature	R = 0.1	66±7 ÷ 100±12 144±7 220±6

When comparing the number of cycles to the initial failure during thermal shock testing (Figure 2) it is clear that the best thermal shock resistance was achieved by alumina coatings. Alumina has a very good thermal conductivity, which is considerable importance in comparison to other tested materials in this study. However, it is necessary to take into account the substrate material and the shape and dimensions of test bars.

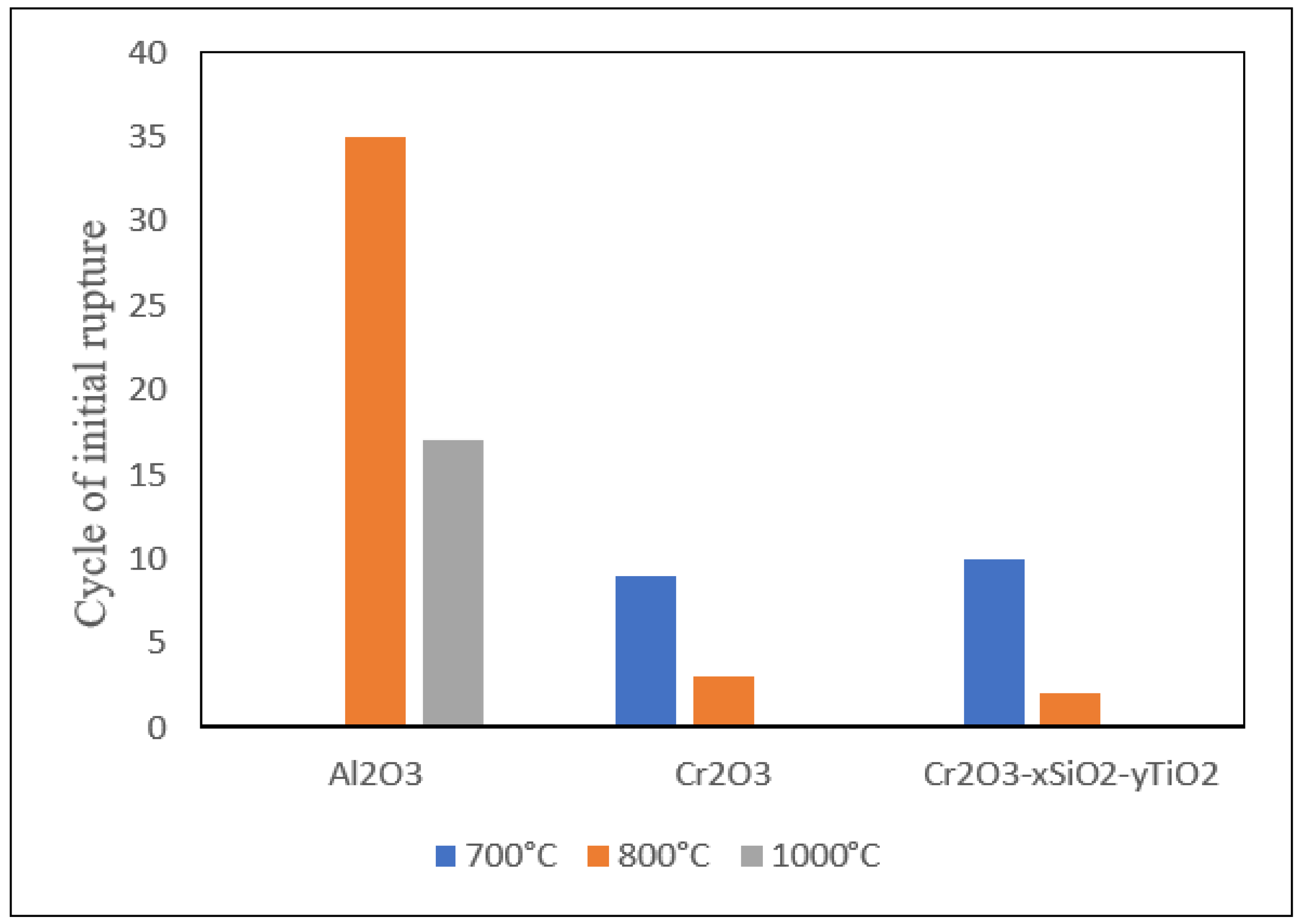

Figure 2. Results of thermal shock tests

CONCLUSIONS

This study was focused on the application of infrared thermography in cyclic load and thermal shock testing of steel samples with ceramic coatings. Alumina, chromia and Cr2O3-5SiO2-3TiO2 coatings were deposited by cascaded plasma torch on S235JR substrate.

- Fatigue limits were found during cyclic load testing. The results of alumina coatings were not consistent and were lowest of the three tested coatings (66±7 ÷ 100±12 MPa). Chromia reached the fatigue limit of 144±7 MPa and Cr2O3-5SiO2-3TiO2 220±6 MPa.
- Thermal shock testing proved that alumina withstands high temperatures the best out of the tested coatings. Cracks in Cr2O3 and Cr2O3-5SiO2-3TiO2 coatings initiated after similar number of cycles.
- Different separation processes of the coatings occurred. In the case of Al2O3 and Cr2O3-5SiO2-3TiO2 the coatings gradually separated in plates while in Cr2O3 the material separated and rapidly flew out of the sample in small individual pieces.

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