Key Engineering Materials Vols 368-372 (2008) pp 1862-1865 Online: 2008-02-11
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doi:10.4028/www.scientific.net/KEM.368-372.1862

Splat Formation of Plasma Sprayed Functionally Graded YSZ/NiCrCoAlY Thermal Barrier Coatings

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Keywords: Thermal barrier coatings; Process parameters; Splat formation

Abstract. Splat morphologies of YSZ/NiCrCoAlY TBCs by plasma spray were characterized using SEM. Based on some assumptions, plasma jet temperature field was established by numerical simulation and the effects of spray parameters are individually studied to optimize the spray process parameters. Furthermore, the interaction wetting ability was taken into account in order to investigate the interaction effect between ZrO_2 and NiCrCoAlY droplets. It shows that T enhances markedly with increasing in I and decreasing in F_{Ar}; while in despite of the insignificant effect of F_{He} on T, the temperature of powder in plasma jet enhances with increasing in F_{He}. As a result of higher thermal conductivity of powder in He plasma gas. NiCrCoAlY droplet impacting solidified NiCrCoAlY splat wets well and spreads fluently while that impacts solidified YSZ splat spreads restrictedly for the poor wetting on the YSZ splat surface.

Introduction

Plasma sprayed graded ZrO_2/NiCrCoAlY thermal barrier coatings (TBCs) have received much attention due to their low thermal conductivity [1,2]. The main characteristics of the coatings lie on their components transition and the splat formation in coatings deposition processes plays an important role in the coating structure and properties. In this paper, graded TBCs were deposited with varying mass fractions of ZrO_2 and NiCrCoAlY. Plasma jet temperature field was established by numerical simulation and splat morphologies were characterized in order to study the effects of spray parameters on splat formation of powders.

Spray Experiment

The plasma process machine used in this work is 5500-2000 made by Praxair-TAFA. The substrate used is polishing stainless steel. The coatings materials used are NiCrCoAlY and yttria stabilized ZrO_2 (YSZ) with nominal particle size ranges of (-20,+45 μm) and (-45,+80μm), respectively. Tab.1 shows the spray parameters in this work. The splat morphology is observed by using SEM.

Numerical Simulation

Degree of powder melting depends on various factors, such as powder size, dwell time in plasma gas flow and plasma gas flow temperature. Spray process parameters have a significant effect on plasma gas flow temperature. The K-ε equation and chemical reaction equation are developed based on some assumptions brought forward by FAN Qun-bo [3].

Tab.1 Plasma spray parameters used to YSZ/NiCrCoAlY TBCs

Powder component	Plasma current I [A]	Primary gas Ar low rate F_A [SCFH]	Secondary gas He flow rate F_{He}/ [SCFH]	Feeding rate [RPM]	Carrier gas [SCFH]	Net engergy [KW]
20%YSZ/80%NiCrCoAlY	600	120	15	5	11	10.5
40%YSZ/60%NiCrCoAlY	700	110	15	5	11	11.9
60%YSZ/40%NiCrCoAlY	700	100	25	5	11	12.6
80%YSZ/20%NiCrCoAlY	800	85	35	5	11	14.1

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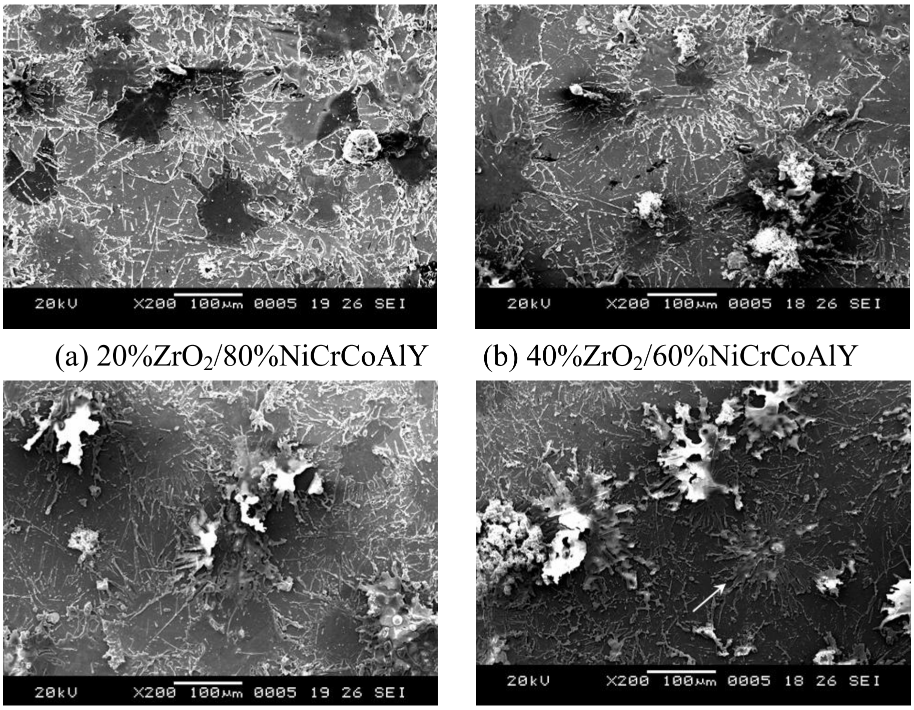

(a) 20%ZrO_2/80%NiCrCoAlY (b) 40%ZrO_2/60%NiCrCoAlY

(c) 60%ZrO_2/40%NiCrCoAlY (d) 80%ZrO_2/20%NiCrCoAlY

Fig.1 Splat morphology of ZrO_2/NiCrCoAlY

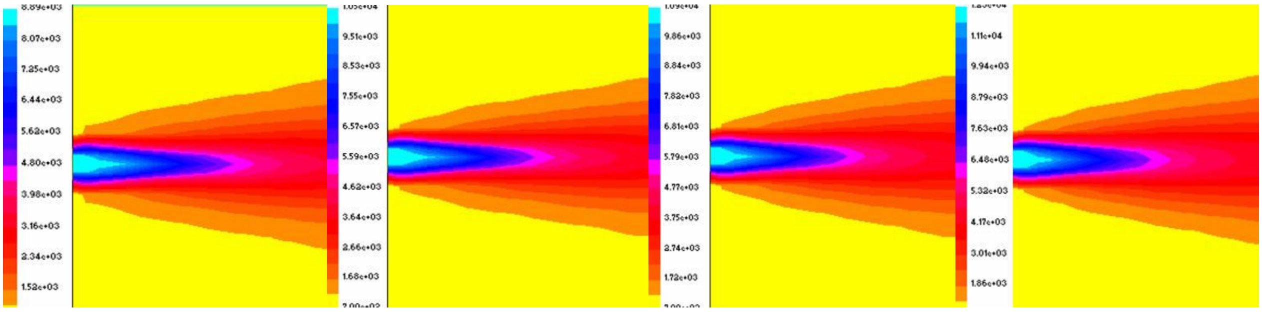

Fig. 2 Plasma jet temperature field by the four process parameters in Tab.1. (a) I=600A, FAr=120SCFH, FHe=15SCFH; (b) I=700A, FAr=110SCFH, FHe=15SCFH; (c) I=700A, FAr=100SCFH, FHe=25SCFH; (d) I=800A, FAr=85SCFH, FHe=315SCFH.

ANSYS/LS-DYNA, a computational program using the finite element method, is used to solve these above equations. In the computational model, the direction alone and vertical to gun axis are defined as X axis and r axis in rectangular coordinates with the area plotted by 80 lines in X axis and 50 lines in r axis and the center put on plasma gun exit. The area is 80×80mm.

Results

Splat morphology. Fig. 1 shows the splat formation SEM photographs of varying mass fractions of YSZ and NiCrCoAlY deposited by plasma spray process parameters shown in Tab.1. According to the Tab.1, when increasing the ratio of YSZ by 20 percent, increasing I and F_{He} and decreasing F_{Ar}, YSZ powder melt better, as seen in the Fig. 1. A relatively complete ball YSZ powder can be seen (shown in Fig.1a) and the size of YSZ powder un-melted is big. The size of un-melted one in 40% YSZ /60% NiCrCoAlY gets smaller (shown in Fig.1b) and its shape is quite different from original ball powder. Likewise, Fig.1c shows that size of un-melted YSZ powder in 60% YSZ /40% NiCrCoAlY get further smaller and even certain big size original YSZ powder melts totally. Splat formation morphology of 80% YSZ /20% NiCrCoAlY is similar to that of 60% YSZ /40% NiCrCoAlY, as shown in Fig.1d. Original YSZ powder that can melt totally is much bigger than that shown in Fig.1c.

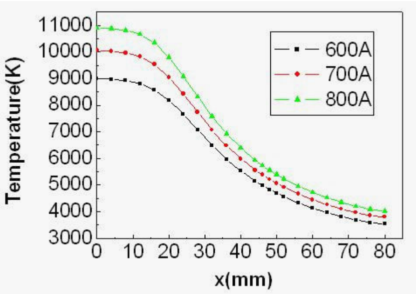

Fig. 3 The effect of plasma flow current on plasma jet temperature

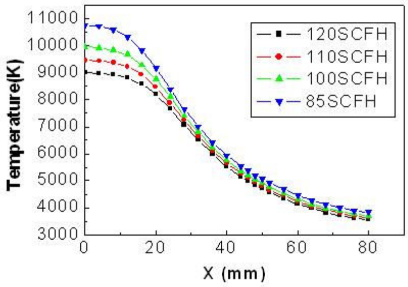

Fig. 4 The effect of primary gas flow rate on plasma jet temperature

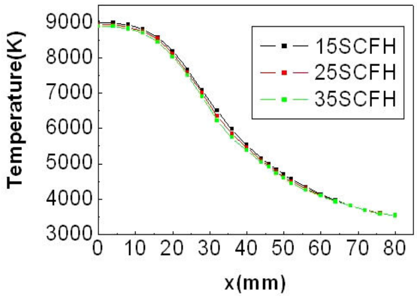

Fig. 5 The effect of secondary rate gas on plasma jet temperature

Fig. 2 shows the results of the corresponding plasma jet temperature fields mentioned above in Fig. 1. The horizontal X axis stands for distance from one position on gun axis to gun exit and the vertical Y axis stands for plasma jet temperature (T). The temperature at gun exit is defined as T_0. With respect to Fig.2a-d, T_0 demonstrates the increasing tendency in spray process parameters in Tab.1, which reaches individually 8890K, 10500K, 10900K and 12300K. Furthermore, the same tendency appears at each value along X axis. In conclusion, increasing I and F_{He} and decreasing F_{Ar}, T takes on an increasing tendency. In hotter plasma jet background, thermal conductivity from jet to powder is so effective that powder melts better and splat spreads more easily.

Fig. 2 shows the change of T when I, F_{Ar} and F_{He} change simultaneously in the course of spraying TBCs. But it needs further study to find how each one of these regulable process variables works on the change of T and how to optimize spray parameters. The effects of I, F_{Ar} and F_{He} on T are simulated individually based on experiment processes in Tab.1, the result is shown in Fig. 3-5. Fig. 3 shows T_0 enhances by 1000 degree when I increases by 100A in the range of 600A to 800A. The difference in temperature owing to increasing in I declines along X axis. But the difference in temperature remains 300K when distance X reaches 80mm. Consequently, I plays an important role in T. Fig. 4 shows that T_0 decreases with increasing F_{Ar} and the difference in temperature gets to 500 K ~ 700K when F_{Ar} change by 10 SCFH. But the difference in temperature declines quickly and when X value is above 20mm, which indicates the weak effect of F_{Ar} on T. Fig. 5 shows F_{He} has the same effect on T with F_{Ar}, but the difference in temperature caused by the F_{He} change is insignificant compared to Far. The three temperature lines are close to each other, indicating weak effect of F_{He} on T.

Regardless of uncertain factors, such as powder size and dwell time in plasma jet, hotter plasma jet makes powder conduct heat more effectively and melt better, which is good for splat formation after impacting substrate. According to Fig. 3 and Fig. 4, T enhances with increasing in I and decreasing in F_{Ar}. Though the weak effect of F_{He} on T, temperature of powder in plasma jet enhances with increasing in F_{He}, as a result of higher thermal conductivity of powder in He plasma gas that is almost 10 times higher than that in Ar plasma gas [4,5].

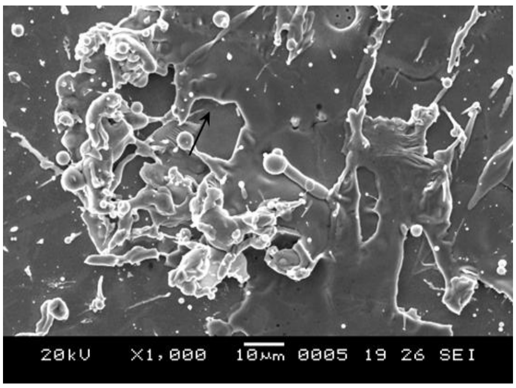

Fig. 6 Interaction between NiCrCoAlY splats in course of spraying TBCs

Interaction effect of YSZ and NiCrCoAlY splat formation. As the formation and solidification time is extremely short in the course of plasma spray, it is impossible for the later splat to deposit on the former un-solidified splat, which means that splat impact behavior is independent in the time magnitude [6]. The final splat morphology is related to interface wetting ability between coating powder and substrate [7,8]. Fig.6 shows NiCrCoAlY droplet wets well and spreads fluently when it impacts former solidified NiCrCoAlY splat, expect for the interrupt of some little satellites around the former splat(see the mark of the arrow in Fig. 6). However, the interface wetting ability between

YSZ and NiCrCoAlY is so poor that NiCrCoAlY droplet impacting solidified YSZ splat spreads not only undergoing the interference of little satellites around the YSZ splat but also suffering from the poor wetting on the YSZ splat surface. Fig. 7 shows that there are “fingers” at the brim of NiCrCoAlY owing to poor wetting on the YSZ splat.

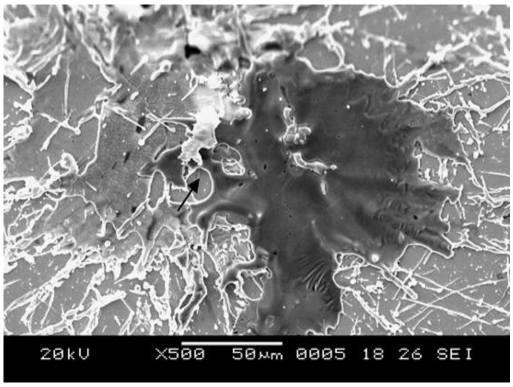

Fig. 7 Interaction between NiCrCoAlY and ZrO_2 splats in course of spraying TBCs

Conclusions

Splat morphologies in YSZ/NiCrCoAlY TBCs plasma sprayed were characterized by using SEM. In order to analyze the effects of process parameters on splat formation, plasma jet temperature field was established by numerical simulation based on some assumptions. Moreover, the effects of plasma current (I), primary gas Ar flow rate (F_{Ar})and secondary gas He flow rate (F_{He})on plasma jet temperature were individually studied to optimize the process parameters. Furthermore, the interaction wetting ability between different materials was taken into account to study the interaction effect between ZrO_2 and NiCrCoAlY droplet. The results show that with increasing in I and decreasing in F_{Ar} plasma jet temperature T enhances markedly; while in spite of the insignificant effect of F_{He} on jet temperature, temperature of powder in plasma jet enhances with increasing in F_{He}, on account of higher thermal conductivity of powder in He plasma gas. NiCrCoAlY droplet impacting solidified NiCrCoAlY splat wets well and spreads fluently while that impacting solidified YSZ splat spreads restrictedly for its poor wetting on the YSZ splat surface.

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High-Performance Ceramics V
10.4028/www.scientific.net/KEM.368-372

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