Formation Mechanism of Al₂O₃-YAG Amorphous Ceramic Coating Deposited via Atmospheric Plasma Spraying

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Abstract

This study mainly investigated the formation mechanism of Al_2O_3 -YAG($\text{Al}_5\text{Y}_3\text{O}_{12}$) amorphous coating prepared by atmospheric plasma spraying. Nano and micro-sized powders with low eutectic point ratio were selected as raw materials for comparison. XRD, SEM and EBSD were used to analyze the phase composition, morphologies, phase distribution and structure of the coating. The crystal structures of the possible existed phases were studied to analyze the crystallization chemistry of powder droplets. It is concluded that the composition ratio of powders and particle size should be also considered as the key factors for the preparation of amorphous coatings besides the high enthalpy and ultra-fast cooling rate of thermal spray technology. The as-sprayable powder chose multiple components with low eutectic point ratio distributed uniformly at nano-scale or sub-micro scale, and can reacted to form the new phase crystal with high coordination numbers of cations.

1. Introduction

Amorphous materials have the characteristic of long-range disordered structure and short-range ordered clusters, and possess scientific and engineering interest for decades[1, 2]. As one of the numerous amorphous materials, inorganic amorphous coatings have been widely used in mechanical, electrical, magnetic, wear-resistant and anti-corrosion fields[3–5]. The common inorganic amorphous coatings are mainly amorphous alloys[6–9], such as Fe-based, Ni-based and Co-based amorphous alloys. However, in the early research of amorphous alloy, because the cooling speed of molten metal powder was very fast, the amorphous alloys were mostly formed in the shape of thin strip or filament, and their application scope was greatly limited due to the small size [2, 5]. Therefore, the amorphous formation mechanism of amorphous alloys had been deeply studied to prepare the bulk amorphousness. And it is generally believed that as long as the cooling rate of the melt is fast enough, the melt of all the substances can form amorphousness[10, 11]. Nevertheless, not every preparation method can achieve the sufficient cooling rate in the actual preparation of amorphous alloys. According to the preparation results of multiple series of amorphous alloys, Inoue[12] proposed the three requirements for the fabrication of amorphous alloys: ①The alloy must be a multi-element system composed of more than three elements; ②The atomic size ratio of the main constituent elements in the alloy is greater than 12%; ③The three main constituent elements in the alloy have a negative mixing enthalpy. The summary of this law provides empirical guidance for the preparation of amorphous alloys. However, the glass transition temperature of amorphous alloys is generally not high ($300 \sim 600^\circ\text{C}$)[8, 13–16], and the initial crystallization activation energy of them is also low (No more than 600 kJ/mol) [17–20]. Therefore, the stability of these amorphous alloys was poor under harsh service conditions, which changed the microstructure of the coating and further affected the performance of the coating.

Recently, some manufactured amorphous ceramic coatings have been deposited. Noticeably, these amorphous ceramic coatings have high crystallization temperature[21–24], which make them have excellent microstructure stability in a wide temperature range for the application under harsh services conditions. In our previous work, the Al_2O_3 -YAG amorphous ceramic coating was deposited via

atmospheric plasma spraying (APS) used the $\text{Al}_2\text{O}_3/\text{YAG}$ powders. The glass transition temperature of the Al_2O_3 -YAG amorphous coating was 905.5°C at $5^\circ\text{C}/\text{min}$, and the initial crystallization activation energy of that was 807.8 kJ/mol by Kissinger method, so Al_2O_3 -YAG amorphous ceramic coating had better high temperature microstructure stability than other 30 kinds of amorphous materials [21]. Moreover, this coating possessed greater crack propagation resistance and lower wear rate under severe wear conditions with high PV values (P: contact pressure; V: friction velocity) than conventional crystalline oxide ceramic coatings (such as Al_2O_3 coating, Al_2O_3 - Cr_2O_3 coating)[25, 26]. The crack propagation resistance was due to the existence of amorphous phase, which increased the crack growth tolerance of the coating and the ability of plastic deformation. Therefore, as-sprayed Al_2O_3 -YAG amorphous ceramic coating with high content of amorphous phase is expected to be used under thermal-mechanical coupling harsh conditions with high PV value. However, the formation mechanism of amorphous ceramic coating is still ambiguous. In order to better guide the application of Al_2O_3 -YAG amorphous ceramic coating, the formation mechanism of Al_2O_3 -YAG amorphous ceramic coating need to be further studied.

Previous studies suggested that the formation mechanism of amorphous ceramic coatings was due to the thermal spraying with high enthalpy and ultra-fast cooling rate[26, 27]. However, this conclusion was slightly inadequate. It has been publicly reported that the XRD patterns of single Al_2O_3 coating and Y_2O_3 coating prepared by various plasma spraying processes were a mainly crystalline state, some coatings contain nanocrystals and have no obvious characteristics of amorphous phase[28, 29]. Therefore, it is not enough to form the amorphous ceramic coating only with high enthalpy and ultra-fast cooling rate under the current technology. According to the results of reported studies, it is concluded that the ceramic coatings containing the amorphous phase successfully prepared were belong to the multicomponent system like Al_2O_3 - ZrO_2 - Al_2O_3 -YSZ- Al_2O_3 - ZrO_2 - SiO_2 and TeO_2 - Bi_2O_3 - V_2O_5 - Na_2O - TiO_2 [22-24, 30-32]. Especially, the ratio of multi-component in sprayable powders was at low eutectic point, then the amorphous ceramic coating can be successfully prepared. Accordingly, the powders with the low eutectic point ratio combined with thermal spraying technology can be used to fabricate high melting point amorphous ceramic coating. In this study, the Al_2O_3 -YAG amorphous ceramic coating was prepared by plasma spraying, and the main purpose was to study the formation mechanism of the amorphous phase in Al_2O_3 -YAG coating to supply the guidance for the coating application.

2. Experimental Procedure

2.1 Materials and preparation

Commercially available nano-size Al_2O_3 ($D_{50}=76.4\text{ nm}$, Wuxi Tuoboda Titanium dioxide products Co., Ltd., Wuxi, China) and Y_2O_3 powders ($D_{50}=74.2\text{ nm}$, Ganzhou Jiayuan New material Co., Ltd., Ganzhou, China) were used as feedstocks. Before spraying, the powders were mixed uniformly with the low eutectic molar ratio ($\text{Al}_2\text{O}_3:\text{Y}_2\text{O}_3$ were equal to 82:18) to spray granulation. And the granulation powders were further

heat-treated to obtain $\text{Al}_2\text{O}_3/\text{YAG}$ powders for the preparation of $\text{Al}_2\text{O}_3\text{-YAG}$ amorphous ceramic coating, the preparation process can refer to our previous work[33]. The stainless steels (1Cr18Ni9Ti) with the dimension of 30mm×15mm×1.25mm were used as substrate. Prior to spray, the substrates were sandblasted to increase the surface roughness and then cleaned by ultrasonic. The NiCr powders were deposited as bond coating. The $\text{Al}_2\text{O}_3/\text{YAG}$ powders were prepared for $\text{Al}_2\text{O}_3\text{-YAG}$ amorphous coating. The powders were deposited by the Multicoat atmospheric plasma spraying system equipped with F4MB-XL gun (Sulzer Metco AG, Wohlen, Switzerland). The spraying parameters are listed in Table 1. Meanwhile, the micro-sized Al_2O_3 ($D_{50}= 17.2\mu\text{m}$, Shenyang emery wheel factory, Shenyang, China) and Y_2O_3 powders ($D_{50}= 39.0\mu\text{m}$, Jinzhou Jinjiang Spraying Material Co. Ltd, Jinzhou, China) were mixed uniformly with low eutectic molar ratio to prepare $\text{Al}_2\text{O}_3\text{-Y}_2\text{O}_3$ coating as contrast reference.

Table 1.

Plasma spraying parameters operated in this study.

Parameters	Bond coating	Top coating
Arc current/A	580-620	640~680
Power, kW	40~45	45~50
Primary plasma gas (Ar), slpm	55~60	46~50
Secondary plasma gas (H_2), slpm	7~9	8~10
Carrier gas (Ar), slpm	3~4	3.8~4.2
Powder feed rate, g/min	10~20	30~40
Spray distance/mm	100~120	100~120

2.2 Coating characterization

The phase composition of powders and coatings were characterized by X-ray diffraction (XRD, D/Max-2550, Rigaku, Tokyo, Japan) with the 2θ range of $10^{\circ}\text{~}80^{\circ}$ and the scanning speed was $2^{\circ}/\text{min}$. The morphologies of coatings were observed by scanning electron microscope (SEM, TM3000, HITACHI, Tokyo, Japan) with Energy disperse spectroscopy (EDS). Electron backscattered diffraction (EBSD) technology was carried out to analyze the phase structure in the coatings preparation. Prior to EBSD testing, ion beam polishing was necessary for coating samples. To better analyze the crystallization chemistry behavior of powder droplets in the deposition process, the software Diamond 3.2 was used to draw the crystal structure of the phase involved in this study.

3. Result And Discussion

3.1 Phase composition analysis

The phase composition of powders and corresponding coatings (Al_2O_3 -YAG and Al_2O_3 - Y_2O_3) were displayed in Fig. 1(a) and (b). As illustrated in Fig. 1(a), a big bulge appeared in the Al_2O_3 -YAG coating, indicated that there was the amorphous phase existed and the content of amorphous phase was about 80%. The crystallization diffraction peaks of α - Al_2O_3 (rhombohedral) and YAG (cubic) also existed in the Al_2O_3 -YAG coating, which originated from un-melted powders or the recrystallization of the droplets. Notably, there were no γ - Al_2O_3 (cubic) in as-sprayed Al_2O_3 -YAG coating, while the α - Al_2O_3 had undergone phase transformation to γ - Al_2O_3 in Al_2O_3 - Y_2O_3 coating. It is widely accepted that the lower critical nucleation energy between liquid and solid of γ - Al_2O_3 than that of α - Al_2O_3 is the main reason why γ - Al_2O_3 is preferential forming in the coating[34,35]. However, there had no γ - Al_2O_3 in Fig. 1(a), so it speculated that the crystallization diffraction peaks of α - Al_2O_3 might be from the un-melted powders, and the component of α - Al_2O_3 in the droplets not crystallized or crystallized very little, so the crystallization diffraction peaks of YAG might be also from the un-melted powders. Beyond that, the c - Y_2O_3 (cubic) also transformed to m - Y_2O_3 (monoclinic) in Al_2O_3 - Y_2O_3 coating. Be similar to γ - Al_2O_3 , the m - Y_2O_3 was also formed. Noticeably, the crystallization diffraction peaks of Al_2O_3 - Y_2O_3 coating in Fig. 1(b) were broadened, which meant some nanocrystals existed in the coating. The compounds of $\text{Al}_2\text{Y}_4\text{O}_9$ (YAM)□ AlYO_3 (YAP) and $\text{Al}_5\text{Y}_3\text{O}_{12}$ (YAG) were not found in Fig. 1(b), which indicated that micro-sized α - Al_2O_3 and c - Y_2O_3 powders hardly reacted during deposition, so the deposition process of Al_2O_3 / Y_2O_3 powders in plasma spray was mainly belong to physical changes. Moreover, the existence of α - Al_2O_3 and c - Y_2O_3 indicated that there might also had un-melted powders in Al_2O_3 - Y_2O_3 coating.

3.2 Micro-morphologies of as-sprayed coatings

Fig. 2 showed the micro-morphologies of as-sprayed Al_2O_3 -YAG amorphous coating. The coating was deposited on the 1Cr18Ni9Ti substrate and the thickness was about 300 μm . The characteristics of most droplet spreading were obviously observed in the surface morphologies of the coating. Beyond that, there were few particles in the yellow circle in Fig. 2(b), which might be caused by the impact crushing of un-melted granulate powders. Some un-melted areas appeared in the cross-sectional morphologies, which may be explained that the part of powders was insufficiently heated during deposition. Based on this result, the crystallization diffraction peaks of α - Al_2O_3 and YAG that existed in Fig. 1(a) were supposed to be from un-melted powders. Meanwhile, a few micro-cracks appeared in the cross-sectional morphologies of Al_2O_3 -YAG coating, which may result from the volume shrinkage due to the rapid cooling of the droplets during deposition. Moreover, there had some bright or dark tiny stripes distributed in the cross-sectional morphologies. The result of EDS showed that the bright stripes contained higher Y element content, which denoted the YAG crystalline phase. Similar stripes features have been found in the publicly reported about some amorphous coatings, but there had no crystal diffraction peaks in the XRD pattern

of these coatings[36,37]. Hence, these stripes in Fig. 2(d) might be the melted elements in amorphous phase were not uniformly distributed or nanocrystals from recrystallization.

The morphologies of as-sprayed $\text{Al}_2\text{O}_3\text{-Y}_2\text{O}_3$ coating were displayed in Fig. 3. According to the principle of backscattered electron imaging, Al_2O_3 and Y_2O_3 can be easily distinguished. In the surface morphologies of $\text{Al}_2\text{O}_3\text{-Y}_2\text{O}_3$ coating, the distribution of Y_2O_3 was not uniformly. Moreover, the coating cross-sectional morphologies also had bright and dark stripes, and the bright stripe was Y_2O_3 while the dark one was Al_2O_3 . Comparing to the $\text{Al}_2\text{O}_3\text{-YAG}$ coating, the difference was that there were more stripes in the $\text{Al}_2\text{O}_3\text{-Y}_2\text{O}_3$ coating and the stripes size was larger, which caused by large particle size of powder. Furthermore, the characteristics of the un-melted region did not be clearly observed in the SEM image of the coating although the powder was presumed not completely fused due to the reservation of $\alpha\text{-Al}_2\text{O}_3$ and $\text{c-Y}_2\text{O}_3$ in the coating.

3.3 The phase distribution of as-sprayed coating

Fig. 4 demonstrated EBSD images of $\text{Al}_2\text{O}_3\text{-YAG}$ amorphous ceramic coating. Most of the area in the image was black due to the 100nm resolution of EBSD, which indicated the amorphous phase and nanocrystals (no more than 100nm) were not collected. Notably, the bright and dark tiny stripes from $\text{Al}_2\text{O}_3\text{-YAG}$ amorphous coating in Fig. 2(d) were also not found, which also proved that the tiny stripes may be from the melted elements non-uniformly distributed in amorphous phase or nanocrystals from recrystallization. There only had $\alpha\text{-Al}_2\text{O}_3$ and YAG in the un-melted area and not found $\gamma\text{-Al}_2\text{O}_3$, so the speculation proposed in section 3.1 that the component of $\alpha\text{-Al}_2\text{O}_3$ not crystallized or crystallized very little was right.

The EBSD images of as-sprayed $\text{Al}_2\text{O}_3\text{-Y}_2\text{O}_3$ coating were revealed in Fig. 5. The results of phase detection showed that there were $\text{m-Y}_2\text{O}_3$ and $\gamma\text{-Al}_2\text{O}_3$ beside the initial phase of $\alpha\text{-Al}_2\text{O}_3$ and $\text{c-Y}_2\text{O}_3$. From Fig. 5(a), the deposition of the powder droplet was mainly in the form of lamellar stacking, and there were many voids between the lamellar structures. Moreover, it can be clearly seen that the edge of the voids was dominated by small grains, so the voids may be nano-crystals or amorphousness. After being sprayed, the amount of $\alpha\text{-Al}_2\text{O}_3$ phase in $\text{Al}_2\text{O}_3\text{-Y}_2\text{O}_3$ coating decreased a lot, and most of $\alpha\text{-Al}_2\text{O}_3$ transformed to $\gamma\text{-Al}_2\text{O}_3$, so the component of $\alpha\text{-Al}_2\text{O}_3$ phase in droplets might mainly be formed to $\gamma\text{-Al}_2\text{O}_3$. While the residual $\alpha\text{-Al}_2\text{O}_3$ phase in the coating might be dominated from un-melted powders. Of course, the $\alpha\text{-Al}_2\text{O}_3$ phase can also be reserved by increasing the interface temperature between liquid and solid[38,39]. By contrast, there were not so much $\text{c-Y}_2\text{O}_3$ transformed to $\text{m-Y}_2\text{O}_3$, but the $\text{m-Y}_2\text{O}_3$ was dominated by small grains and also mainly appeared in the edge of the voids.

In the analysis of Fig. 1(b), the $\text{YAM} \rightarrow \text{YAP}$ and YAG were not found, so the deposition process of $\text{Al}_2\text{O}_3/\text{Y}_2\text{O}_3$ powders in plasma spray speculated might belong to physical changes. This phenomenon was mainly attributed to the fact that the mechanically uniformly mixed $\alpha\text{-Al}_2\text{O}_3$ and $\text{c-Y}_2\text{O}_3$ powders

were not uniformly distributed in nano-scale or sub-microscale. The distance of different phases between the powder droplets was large so that the internal ions cannot effectively diffused and reacted with each other. Actually, the effectively diffusion and reaction of ions only occurred at the interface of different phase droplets, but the reaction was incomplete due to the insufficient reaction time during deposition and improper size ratio of powder[40]. The crystallization process of droplets was not easy at the edge of the lamellar structures from Fig. 5. The reason was that the micro-powders of Al_2O_3 and Y_2O_3 reacted, but the new phases (YAM, YAP or YAG) formed by reaction maybe not easy to crystallize. It was verified that the YAG coating was prepared by plasma spraying was dominated by amorphousness from XRD pattern[41,42]. Thusly, the crystallization resistance of droplets increased as the more sufficient mutual diffusion of Al_2O_3 and Y_2O_3 at the nano-scale or sub-microscale. From this point of view, the Al_2O_3 -YAG amorphous ceramic coating can be successfully deposited was ascribed to the fact that the particle size of the feedstock powder was nanometer or sub-micrometer and mixed more uniformly. Therefore, the crystallization resistance of Al_2O_3 /YAG powders droplets was large during deposition. However, the phenomenon that the powder droplets with different phases distributed uniformly were difficult to crystallize was not be explained clearly. The possible reason may be related to the chemical behavior of crystallization. Beyond that, the composition ratio of powders and particle size can be also considered as the key factors for the preparation of amorphous coatings.

3.4 Crystallization chemical process in powder droplets solidification

From the result of XRD and EBSD, the $\alpha\text{-Al}_2\text{O}_3$ was heated and turned into droplet, the droplet transformed as $\gamma\text{-Al}_2\text{O}_3$ in recrystallization. Many literatures have explained this phenomenon from the viewpoint of nucleation energy, but few reports have considered it from the perspective of crystallization chemistry of melt. Usually, low coordination number means low probability of between ions meeting in the melt during crystallization [43]. Fig. 6 displayed the schematic diagram of the crystal structure of the possible existed phases in this study. The first row in Fig. 6 is the initial phases crystal structure of the powders used in this study. The second row is new -generated phases crystal structure in the coating. The second row is the possible mesophases crystal structure from the chemical reaction of Al_2O_3 and Y_2O_3 . Table 2 listed the coordination number of Al element or Y element in above-mention crystals. The coordination number of Al element in $\alpha\text{-Al}_2\text{O}_3$ is 3 and that in $\gamma\text{-Al}_2\text{O}_3$ is 4, so the reason that $\alpha\text{-Al}_2\text{O}_3$ droplets transformed to $\gamma\text{-Al}_2\text{O}_3$ is that because Al element has higher coordination number and had more chance to form lattice in $\gamma\text{-Al}_2\text{O}_3$, so the $\gamma\text{-Al}_2\text{O}_3$ preferentially crystallized. The coordination number of Y element for c- Y_2O_3 and m- Y_2O_3 is 6, so the droplets of c- Y_2O_3 transformed to m- Y_2O_3 or recrystallized to c- Y_2O_3 . Notably, the density of m- Y_2O_3 was less than c- Y_2O_3 in table 2, which meant m- Y_2O_3 has less stacking density than c- Y_2O_3 , so the m- Y_2O_3 is probably easier to form. Specially, the coordination number of Al and Y element in YAG was really high, but the Al_2O_3 /YAG powders via plasma spray formed to amorphousness. The coordination number of Al and Y element was also high in YAM and YAP crystals. And the strip-like voids

in Fig. 5 were that the new phase like YAM, YAP and YAG reacted by Al_2O_3 and Y_2O_3 were not easy to crystallize due to ultra-fast cooling of plasma spraying. Therefore, higher coordination numbers may be more preferable to form amorphousness in a particular situation, which seems conflict to the viewpoint that low coordination number denotes low probability between ions meeting during crystallization.

Table 2

The relevant crystallographic data from some compounds in this study

Compound	Crystal system	Space group	Density, g/cm ³	Coordination number		Ref
				Al	Y	
$\alpha\text{-Al}_2\text{O}_3$	Rhombohedral	R-3c	4.05	3	-	[44]
$\gamma\text{-Al}_2\text{O}_3$	Cubic	Fd-3m	3.67	4	-	[45]
$\text{c-Y}_2\text{O}_3$	Cubic	Ia-3d	5.03	-	6	[46]
$\text{m-Y}_2\text{O}_3$	Monoclinic	C 2/m	4.98	-	6	[47]
YAG	Cubic	Ia-3d	4.12	4, 6	8	[48]
YAP	Orthorhombic	Pbnm	5.35	6	6	[49]
YAM	Monoclinic	P1 21/c1	4.52	4	6,7	[50]

According to other research[51,52], the phase diagram of the Al_2O_3 - Y_2O_3 system was drawn in Fig. 7. The Al_2O_3 - Y_2O_3 system has four eutectic point. And when the melt simultaneously crystallizes to YAG and Al_2O_3 , this eutectic point has the lowest melting points (1820°C). It is worth noting that the melting point of melt decreases as the melt contains both Al_2O_3 and Y_2O_3 , so the crystallization chemical behavior of different phases will hinder each other's crystallization process can be proved. Fig. 8 illustrated the schematic diagram of possible bonding modes of Al and Y with O in droplet. Although the high coordination number ion/atom means high probability of between ions meeting to form ion groups, low coordination number ion/atom also has chance to bond. The crystal structures formed by different bonding methods are not always stable at a given temperature, and those crystals are easy to transform to the most thermodynamically stable structure at that temperature. For example, $\gamma\text{-Al}_2\text{O}_3$ are preferential crystallization from high temperature to room temperature in APS deposition, but it conflicts to the fact that $\gamma\text{-Al}_2\text{O}_3$ crystal is not stable in high temperature ($\geq 1000^\circ\text{C}$) and can transform to $\alpha\text{-Al}_2\text{O}_3$ at high temperature. One possible explanation is that $\gamma\text{-Al}_2\text{O}_3$ crystal structure can be formed in high temperature, and it is unstable and need time to transform as the more stable structure like $\alpha\text{-Al}_2\text{O}_3$, but it can be reserved due to the insufficient time during the APS deposition. Therefore, the crystal with thermodynamically stable structure is usually not easy to form due to the fact that the formation of

different ion groups also need time to transform to the thermodynamically stable structure, so the crystallization process was hindered.

3.5 The formation mechanism of amorphous phase in Al_2O_3 -YAG amorphous ceramic coating

Fig. 9 displayed the formation mechanism of amorphousness in plasma-sprayed Al_2O_3 -YAG amorphous ceramic coating. The amorphous phase formation process of Al_2O_3 -YAG coating can be summarized as follows: the nano-size or sub-micro size scale uniformly distributed multivariate powders with eutectic molar ratio were rapidly heated and fully melted to form a high temperature melt in the plasma plume, then the molten droplets impacted the surface of the substrate/coating at a high speed and quenched, resulted in a steep temperature gradient between the melt and the deposition interface. The melt possessed priority to form ion/atom groups with high coordination number of cations. Meanwhile, the low coordination number of cations in ion/atom groups also formed. Different ion/atom groups can interfere with each other, which hindered the nucleation and growth of crystals, so that the amorphization can be realized due to the fact that droplets were not structurally regulated within a limited time in ultra-fast cooling process of plasma spraying.

Accordingly, there are three requirements for the formation of Al_2O_3 -YAG amorphous ceramic coating: ☐ A heat source with a high enough temperature can heat the crystal materials to be melt that the internal atoms/ions tend to be disordered. ☐ Ultra-fast cooling rate which makes the internal atoms/ions of the melt have insufficient time to diffuse into the lattice of crystal and crystallize. ☐ The as-sprayable powder should chose multivariate powders with low eutectic point ratio distributed uniformly at nano-scale or sub-micro scale and can be reacted to form the new phase crystal with high coordination numbers of cations.

4. Conclusion

The formation mechanism of amorphous phase in plasma-sprayed Al_2O_3 -YAG amorphous ceramic coating prepared by Al_2O_3 /YAG powder with low eutectic point was mainly investigated, and the Al_2O_3 / Y_2O_3 micro-powder as a contrast to prepare crystalline coating. Different to other research, this study revealed the effect of melt crystallization chemistry on crystallization process, and proved that the selection of powder also has an important effect on the preparation of amorphous ceramic coating. In summary, there have three requirements to prepare Al_2O_3 -YAG amorphous ceramic coating in preparation technology and as-sprayed powder. The preparation technology requires high enthalpy and ultra-fast cooling rate. And the as-sprayable powder should choose multivariate powders with low eutectic point ratio distributed uniformly at nano-scale or sub-micro scale and could react to form the new phase crystal with high coordination numbers of cations.

Declarations

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Figures

Figure 1

XRD patterns of the powders and as-sprayed coating: (a) Al_2O_3 -YAG (b) Al_2O_3 - Y_2O_3 .

Figure 2

Micro-morphologies of as-sprayed Al_2O_3 -YAG amorphous ceramic coating: (a)- (b) surface morphologies; (c)- (d) cross-sectional morphologies

Figure 3

Micro-morphologies of as-sprayed $\text{Al}_2\text{O}_3\text{-Y}_2\text{O}_3$ coating: (a)- (b) surface morphologies; (c)- (e) cross-sectional morphologies; (f) EDS of the coating in (d)

Figure 4

EBSD images of as-sprayed Al₂O₃-YAG amorphous ceramic coating

Figure 5

EBSD images of as-sprayed Al₂O₃-Y₂O₃ coating

Figure 6

The schematic diagram of the crystal structure of the possible existed phases in this study

Figure 7

Phase diagram of the Al_2O_3 - Y_2O_3 system

Figure 8

Schematic diagram of possible bonding modes of Al and Y with O in droplet

Figure 9

The formation mechanism of amorphous phases in plasma-sprayed Al_2O_3 -YAG amorphous ceramic coating