The Effect of In-flight Bulk Metallic Glass Particle Temperature on Impact Behavior and Crystallization

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Abstract

NiTiZrSiSn bulk metallic glass powder was produced using inert gas atomization and then was sprayed onto a SS 41 mild steel substrate using the kinetic spraying process. Through this study, the effects of thermal energy of in-flight particle and crystallization degree by powder preheating temperature were evaluated. The deformation behavior of bulk metallic glass is very interesting and it is largely dependent on the temperature. The crystalline phase formation at impact interface was dependent on the in-flight particle temperature. In addition, variations in the impact behavior need to be considered at high strain rate and in-flight particle temperature.

Keywords : Kinetic spraying, Bulk metallic glass, Deformation, Strain rate, Adiabatic shearing

1. Introduction

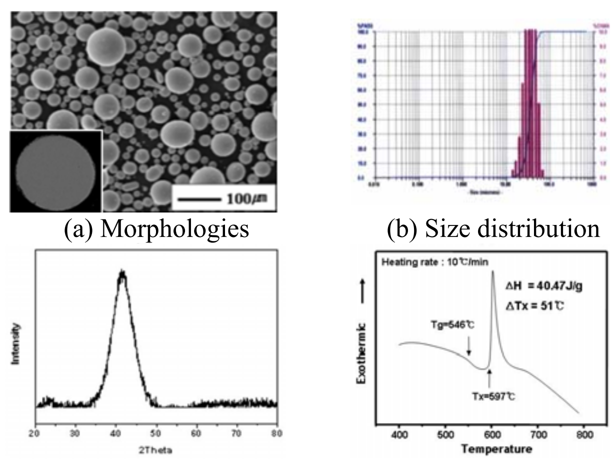
Dissimilar to thermal spraying processes, the kinetic spraying is too low to cause thermally activated process such as melting, solid-state phase transformation, grain growth, and high temperature oxidation [1]. Therefore, the kinetic spraying process can be regarded as a spraying forming process for thermally activated processes such as BMG materials [2]. In a real impacting situation, inhomogeneous deformation within an impacting particle is expected. It means that there are stress, strain, and temperature distributions within the particle. Therefore, deformation behaviors at a localized contacting region of an impacting particle are considered to be important for the impacting behavior of the particle in kinetic spraying. The deformation behavior of BMG is very interesting and it is largely dependent on temperature and the strain rate [3]. For the successive deposition of BMG particles in kinetic spraying, strain rate and temperature evolutions and resulting deformation behaviors are key-points.

2. Experimental and Results

NiTiZrSiSn bulk metallic glass feedstock was manufactured using an inert gas atomization method. Mild steel substrates were finely polished for individual particle deposition and coating formation. The process parameters can be seen in Table 1. Other parameters were constant except for the powder preheating temperature. After coating, the coating microstructure and phase identification were conducted by scanning electron microscopy(SEM), x-ray diffractometry(XRD), differential scanning calorimetry (DSC), and transmission electron microscopy(TEM).

Table 1. Process parameters

Gas	Process gas		Powder preheating temp.
	Press.	Temp.	
Helium	29bar	550℃	RT, 450 ºC, 550 ºC



(a) Morphologies (b) Size distribution
(c) Phase (d) DSC curve

Fig. 1. Characteristics of the NiTiZrSiSn bulk metallic glass feedstock.

The characteristics of bulk metallic glass can be seen in Fig. 1. Morphology of particles has spherical having smooth surfaces. Particle size distribution was above 5 μm and below 45 μm. In the x-ray diffraction of the feedstock, a diffuse peak is shown in Fig. 1 (c) and it is a typical diffraction pattern of the amorphous phase. For the thermal analysis, an endothermic heat flux from the glass transition is observed at 546 °C [Tg: glass transition temperature] and an exothermic one from the crystallization starts at 597 °C [Tx: the onset point for crystallization].

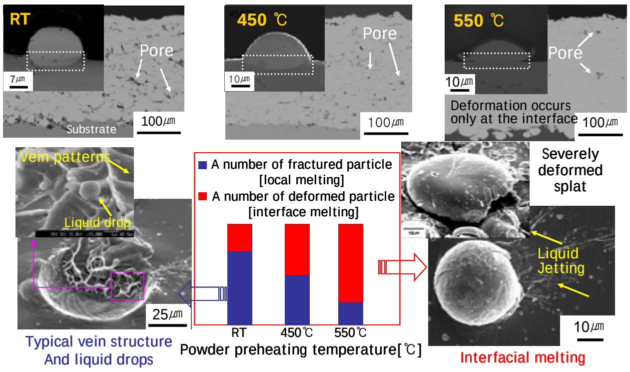
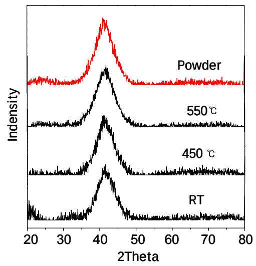


Fig. 2. Cross-sectional morphologies of the individual particle according to powder preheating temperature.

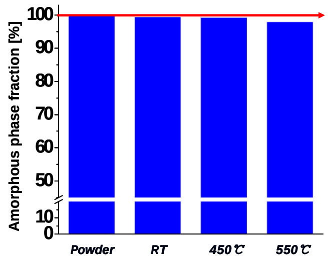
Fig. 2 shows the individual particle deposition behaviors on the SS 41 mild steel substrate and the cross-sectional morphology of the coating according to powder preheating temperature. Basically, the deposition of the bulk metallic glass particle on the SS 41 mild steel is regarded as that of a hard and elastic particle on a soft and plastic substrate. The BMG particle is deeply embedded into the substrate by relaxing the impacting particle energy. The flatten ratio of the splat to impact particle is increased by powder preheating temperature to Tg. It is evident that partial melting of BMG did occur during impacting as shown in Fig. 2: liquid jet between the BMG splat and the substrate and mass flow on the crater. Also, particles without any additional heating showed severe fractures with typical vein structures and liquid drop[4] on the surface. It could be deduced that the pressure building in the impacting splat resulted in the fracture before softening and the fracture caused melting which is typical for the fracture of the bulk metallic glass. The melt seemed to act as a binder for the deposition. For high strain rate, like in kinetic spraying, the heat is adiabatically generated and it reduces the flow stress for deformation, which is known to be adiabatic shearing. Adiabatic softening and adiabatic shear localization play an important role in particle and substrate bonding during the kinetic spraying deposition process.

In order to confirm whether or not crystallization occurred in the coating, XRD, DSC, and TEM were conducted. Amorphous phase fraction was calculated following ref. [5] from DSC data. As shown in Fig. 3(a) and (b), there is little marked difference in phase composition and thermal properties between the feedstock and the coatings in XRD and DSC analysis. However, as the powder preheating temperature increased, nano-crystallization occurred at the localized interface as shown in Fig. 3(c). It could be that nano crystallization occurs due to induced strain and localized heating to above Tx at the localized interface.

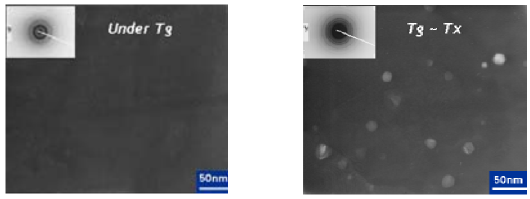
It is suggested that the deposition of elastic bulk metallic glass is determined by adiabatic heat generation, resulting viscous flow and partial melting at the impacting interface.



(a) X-ray diffractometry



(b) Amorphous phase fraction was calculated from DSC data



(c) Transmission electron microscopy

Fig. 3. Characteristics of the as-sprayed coating.

3. Summary

In this study, the effects of additional heating on the individual particle deposition and resulting coating microstructure were investigated. The additional heating for the BMG particle affected the individual particle deposition behavior and the resulting coating microstructure. The amount of deformed area is increasing with particle preheating temperature and coatings are getting denser with increased powder preheating temperature. Moreover, TEM shows that at preheating temperatures above Tg, local crystallization can be observed. It could be that local crystallization occurs due to induced strain and localized heating to above Tx at the localized interface.

4. References

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