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# Structural characterization of plasma sprayed basalt–SiC glass–ceramic coatings

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**Abstract**

In the present study, the effect of SiC addition on properties of basalt base glass–ceramic coating was investigated. SiC reinforced glass–ceramic coating was realized by atmospheric air plasma spray coating technique on AISI 1040 steel pre-coated with Ni + 5 wt.%Al bond coat. Composite powder mixture consisted of 10%, 20% and 30% SiC by weight were used for coating treatment. Controlled heat treatment for crystallization was realized on pre-coated samples in argon atmosphere at 800 °C, 900 °C and 1000 °C which determined by differential thermal analysis for 1–4 h in order to obtain to the glass–ceramic structure. Microstructural examination showed that the coating performed by plasma spray coating treatment and crystallized was crack free, homogeneous in macro-scale and good bonded. The hardness of the coated samples changed between 666 ± 27 and 873 ± 32 $HV_{0.01}$ depending on SiC addition and crystallization temperature. The more the SiC addition and the higher the treatment temperature, the harder the basalt base SiC reinforced glass–ceramic coating became. X-ray diffraction analysis showed that the coatings include augeite [(CaFeMg)–$SiO_3$], diopside [$Ca(Mg_{0.15}Fe_{0.85})(SiO_3)_2$], albite [$(Na,Ca)Al(Si,Al)_3O_8$], andesine [$Na_{0.499}Ca_{0.492}(Al_{1.488}Si_{2.506}O_8$] and moissanite (SiC) phases. EDX analyses support the X-ray diffraction analysis.



*Keywords:* D. Glass–ceramic; SiC; Plasma spray; Coating; Basalt

## 1. Introduction

Glass–ceramic materials are polycrystalline solids with a residual glassy matrix leading to a polycrystalline microstructure that allows achievement of a better performance to abrasiveness and an increased resistance compared to traditional glasses [1]. Conventional glass–ceramics produced in two steps include nucleation and crystal growth. In general, the process is too expensive when the powder used in the process are technical grade oxide, besides the thermal treatments realized for the crystallization treatment of the glass form coating in the glass–ceramic coatings. But, natural volcanic rock powders can be used for glass–ceramic coatings without any nucleation agent and the process would be very cheaper than the glass–ceramics produced from pure oxides [2,3].

The basalt is a volcanic rock which is dark colored, small grain sized. Basalt covers more over than 2.5 billion $km^2$ of earth. Moreover, basalt fundamentally includes $SiO_2$, $Al_2O_3$, MgO, CaO and iron oxides (FeO, $Fe_2O_3$) in addition contain $Na_2O$, $K_2O$, $P_2O_5$, MnO and $TiO_2$ at small amount. Superior abrasion, wear and chemical resistant basalt-based glass–ceramics can be produced from the basalt [4].

Thermal spray is, in many cases, superior to other coating technologies with regard to process control and economic issues [5]. Plasma-sprayed ceramic coatings have been widely used for structural applications in order to improve resistances to wear, corrosion, oxidization, erosion, and heat [6]. Plasma spray processing can provide a reasonable method by which to prepare composite powders. Composite materials have the propensity to improve the mechanical, chemical and thermal behavior by combining materials with distinctive or supplementary properties [7].

In the present study, structural and mechanical properties of the glass–ceramics, produced from different compositions of the mixture of volcanic basalt rocks and SiC powders coated by

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atmospheric plasma spray coating method and effects of the crystallization parameters, were investigated.

## 2. Experimental procedure

Basalt rocks obtained from Konya region of Turkey were chunked and crashed using jaw and conic crushers. It was milled using ring miller and sieved to the grids of −53 and +45 μm for plasma spray coating. Basalt powders used in the coating process were analyzed using Perkin-Elmer 2300 atomic absorption spectroscopy. The chemical compositions of the basalt powders used in the study were given in Table 1. SiC was used as reinforced materials the average particle size of which was −53 μm. AISI 1040 steel was used as a substrate material in the dimensions of 20 mm in diameter and 5 mm in height. Steel samples were cleaned in ethyl alcohol and acetone, ultrasonically for 15 min and then sand blasted with 35 grit alumina. The resulting average roughness of the substrate surface (Ra) after grid blasting that measured Perthometer M4P surface roughness tester is between 3.5 and 4.6 μm. Also, these samples were cleaned again in ethyl alcohol and acetone for 15 min and dried. Ni–5 wt.%Al (METCO 450 NS) was used for the bond coat layer. The torch nozzle used for coatings was METCO 3 MB with 6 mm alloyed Cu nozzle. The position of the injector relative to the nozzle exit was 90°. The injector is in the same axis with torch. Powder unit of injector was METCO 3 MP powder feed unit. The coating operations were performed in the room temperature.

Basalt powder was mixed with 10%, 20% and 30% SiC powder by weight in the rotating chamber for homogenous mixing of the composite powders. Specific masses of SiC and basalts in the powder mixtures are 0.20, 0.42, 0.66 and 0.80, 0.58, 0.34 g/cm$^3$, respectively. Atmospheric plasma spray coating technique was used for coating treatment of the prepared composite powder on bond coated steel samples. Plasma spray coating parameters used in the coating treatment was shown in Table 2. Differential thermal analysis (DTA) was performed on the coated samples for determining the crystallization temperature with heating rate of 15 °C min$^{-1}$ up to 1000 °C temperature using TA instrument thermal analysis device. Coated samples were controlled heat treated for crystallization to produce glass–ceramic coatings at 800 °C, 900 °C and 1000 °C in argon atmosphere by a Protherm tube furnace with a time ranging from 1 to 4 h to promote internal crystallization. Fig. 1 shows the flow chart of SiC reinforced basalt based glass–ceramic coating process. JEOL 6060 scanning electron microscopy (SEM) with energy dispersive X-ray spectroscopy (EDX) and X-ray diffraction analysis (XRD) using Rigaku type diffractometer with a CuK$_\alpha$ radiation, which has a wavelength of 1.54056 Å to analyze phases present in the coatings over a 2$\theta$ range of 10–90° were used for characterization of the coated samples. XRD analysis was also performed for basalt rock. The hardness of basalt-based coating layer was measured on the cross-sections using a Future tech FM 700 Vickers indenter with a load of 10 gf.

Table 1
Chemical composition of the basalt powder.

| Compounds | wt.% |
|---|---|
| $SiO_2$ | 45.88 |
| $Al_2O_3$ | 18.2 |
| $Fe_2O_3$ | 9.95 |
| CaO | 9.28 |
| MgO | 6.62 |
| $K_2O$ | 1.64 |
| $Na_2O$ | 4.76 |
| $P_2O_5$ | 1.04 |
| LOI | 2.63 |

Table 2
Plasma spray coating parameters.

| Coating parameter | Value |
|---|---|
| Plasma gun (MB) | 3 |
| Current (A) | 500 |
| Voltage (V) | 64–70 |
| Gas flow for Ar (l/min) | 50 |
| Gas flow for H (l/min) | 15 |
| Spray distance (mm) | 130 |
| Powder feed rate (g/min) | 39 |
| Carrier gas flow (l/min) | 3–6 |

## 3. Results and discussion

Fig. 2 shows XRD analysis of basalt rock. It was found that the main crystalline phases were albite [(Na,Ca)Al(Si,Al)$_3$O$_8$], anorthite [Ca(Al$_2$Si$_2$O$_8$)], augite [(CaFeMg)–SiO$_3$] and diop-

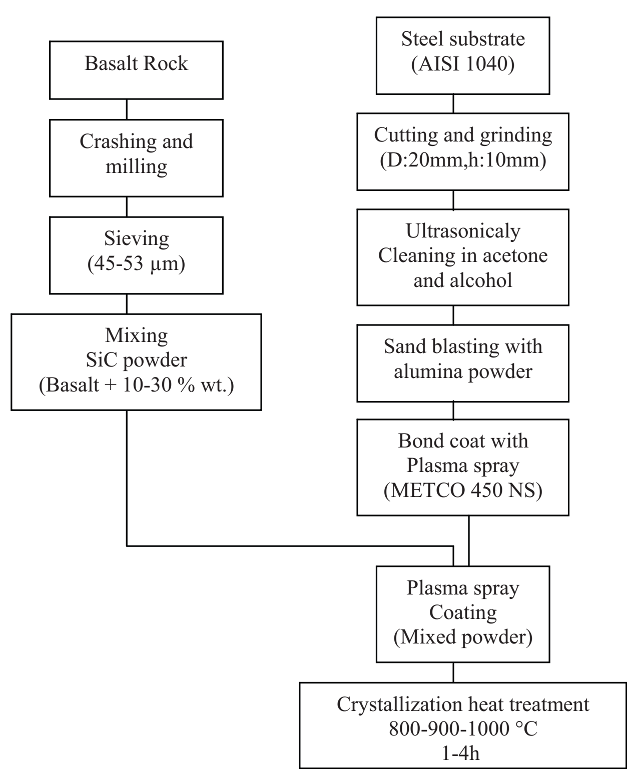


Fig. 1. Flow chart of SiC reinforced basalt based glass–ceramic coating process.