Investigations on (ZrO_2.5CaO+Al_2O_3) appliedon Al6061and Gray cast Iron (GCI) substrates

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Abstract— Identifying the factual structure and mechanical properties plays a very important role before and after thermal spray coatings. This paper addresses best possible methods for the evaluation of Air plasma spray coatings on Al6061and Gray Cast Iron samples. In the present experimental work Alumina plus Calcia stabilized zirconia were used as a top coat, applied on both the samples and only one bond coat i.e.Fe38Ni10Al applied on Gray Cast Iron ,two bond coats namely Al25Fe7Cr5Ni-BC1 & $Al_20_3$30 (Ni20Al)-BC2 applied on Al6061sustrate.In the study it was realized that a very good adhesion exist between substrates and bond coat and little deformities observed between top coat (ZrO_2.5CaO+Al_20_3) & bond coat 2 $Al_20_3$30 (Ni20Al) in case of Al6061.A very Good bonding understood in case of GCI coating systems. A very unique mineral, Tarzhenite phase identified in XRD analysis and it was found that the hardness of the top coat is significantly affected by porosity and the specific weight percentage of Tarzhenite in the coating systems.

Index Terms— Characterization, XRD, Porosity, Hardness.

1 Introduction

Since three decades yttria stabilized zirconia have been applied over hot components viz. internal combustion engines, gas turbines etc.[1,2].Because of its limitation like phase change at elevated temperature, low toughness restricted its applications. Now researchers are looking forward for alternate materials that can overcome such problems.

First results on the microstructural alteration in FeC coated cylinders are published in Hahn et.al [3, 4].The micro structures and mechanical properties of plasma sprayed coating profoundly depends on feedstock morphologies, method of injection of feedstock and plasma spray operating conditions [5,6].Coating properties also depend on the peening effect of the impacting particles on previously deposited coatings i.e over bond coats. The adhesion strength of bond coats with the substrate and top coat with bond coat plays an important role in the strengthening mechanism of the whole coating systems. In recent research works numerical and experimental investigations have been carried out on morphologies of diverse powder materials [7]. Parizi et.al. [8] adopted a numerical simulation technique, using volume of fluid (CFD) technique to explore the characteristics of the substrate surfaces.

2. Experimental Procedure

For the present work Air Plasma Spray Coating methodology adopted. For the present work Alumina plus calcia stabilized zirconia,Alumina(Metco105SFP)and ZrO25CaO (Metco201NS) used in specific percentage acting as top coat hereafter (TC) and Fe38Ni10Al considered as bond coat here after (BC) applied over Gray cast iron and Al6061 substrate. For the coating purpose the samples were tailored into 10×10cm^2 and for characterization of the coating 10×10×5 mm sliced from the above dimension. The sliced samples were polished to get high surface finish later the same sample subjected for scanning electron microscopy for identification of microstructures, porosity analysis followed by X-ray diffractometer (XRD): phase identification, Vickers Micro hardness test were conducted at the cross section of the samples.

The objective of the work is to compare the morphologies, investigate the new phases formed due to solid state reactions, identifying the level of porosity also explore the effect of newly developed phases on micro hardness of the coating samples applied on Al6061 and GCI.

2.1 Sample preparation and coating thickness

The samples Al6061 and Gray cast iron here after (GCI) were first tailored into 10cm×10cm^2 dimension. The samples were girt blasted followed by Air Plasma coating here after (APS) were carried out on each samples for coating purpose. For the characterization, three coating system was developed of varying top coating thicknes.viz.100, 200 and 300µm on both the substrates. Specifications and parameters used during air plasma coating operations shown in table 1.

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No.	Specifications	Parameters
1	Plasma gun	3 Nylon Brush
2	Nozzle Temperature	10,000 0C
3	Current	500 Amps
4	Voltage	65-70 Volts
5	Powder feed	45-45gm / min
6	Spray distance	50.8-78 mm
7	Primery gas(Argon)	3.7 Bar
8	Secondary gas, Hydrogen	3.45 Bar

Table 1: Air Plasma machine Specification

Scanning electron microscopy technique is adopted was adopted to explore the surface characteristic of the top coat of the samples. For the ease of conduction of experiment the samples were sliced into 10×10×5 mm dimensions. Preliminary the cross section of the samples was polished to achieve greater accuracy in the results. The percentage error in the top coatings was measured using empirical relation, for all the three coating systems. The microstructure characterization, porosity, Vicker Micro hardness test was performed on the Clemex CMT.HD model. The Microhardness test was conducted as per ASTM E-384 at 100 kgf, dwell time 10 sec using diamond pyramid indenter (120^0).XRD Analysis was performed on model: Brukar D8 advance, operating with CuKα1 radiation produced at 40 kV and 40mA and scanning of samples were done from 20 and 89.990 in a step width of 0.010360.XRD analysis was based on search match method. An average of three readings was recorded at the transverse section of all the samples during vicker micro hardness test.Porosity analysis was carried out on specific area of the cross section of the samples using CCD Camera.

3. Results and Discussion

3.1 Coating Thickness measurement

Since, 100,200 and 300µm as a top coat was intended to be applied, it was necessary to check its dimensionality. An empirical relation was used (refer equation 1) to evaluate the error percentage. It has been observed that the variation in the top coating thickness was around 39.3%, 4.76% & 8.1% for Al6061 and 39.3%, 13.97% &14.89% in case of gray cast iron for 100,200 and 300 respectively on both the substrates. This error realized due to due to manual spray coatings, which can be overcome by adopting robotic plasma coating method.

$$\frac{Tth - Tact}{Tact} \times 100 \qquad \text{(Eq-1)}$$

3.2 Characteriation

Substrate and bond coat 1,negeligible disparity realized between bond coat 1 and bond coat 2,at the same time noticeable mismatch found between top coat and bond coat 2 in case of Al6061 substrate. The reason of the mismatch attributed to the composition of bond coat with top coat also difference in coefficient of thermal expansion between TC & BC refer (fig.1) initial cracks in 100µm coating system. From fig.4, 5, 6 it was realized that an excellent bonding exist at the interfaces of substrate and bond coat and between bond coat and top coat. It would be appropriate to say that selection of top coat in both the coating system was worthy as there are not many metallurgical problems admitted at the interfaces of both the coating systems.

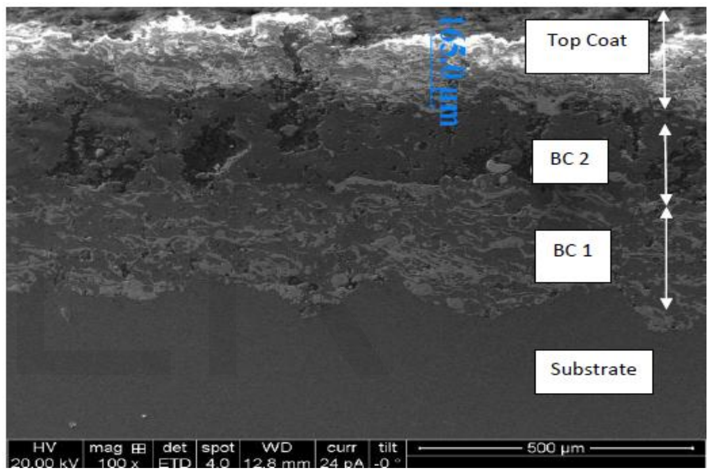

Fig-1 SEM image showing cross section of Al6061 100µm top coat.

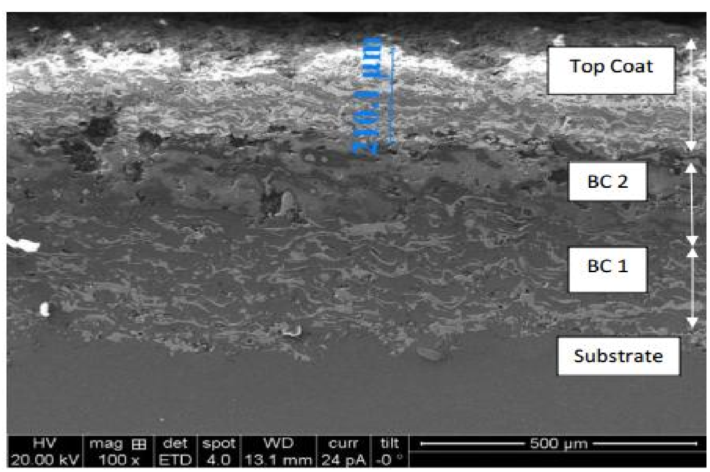

Fig-2 SEM image showing cross section of Al6061 200µm top coat.

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International Journal of Scientific & Engineering Research Volume 7, Issue 5, May-2016
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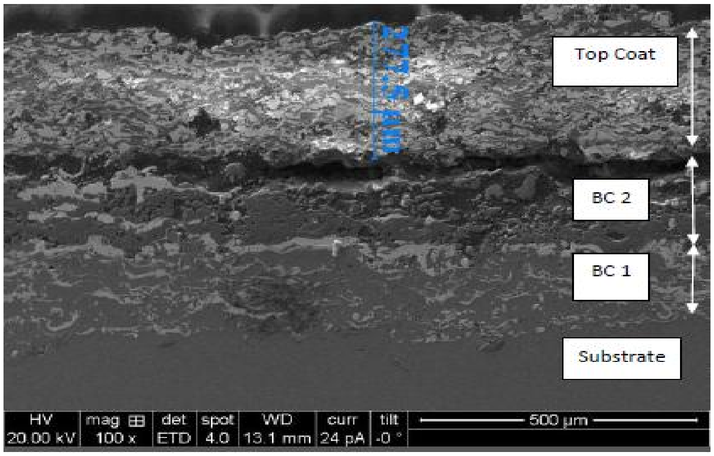

Fig-3 SEM image showing cross section of Al6061 300μm top coat.

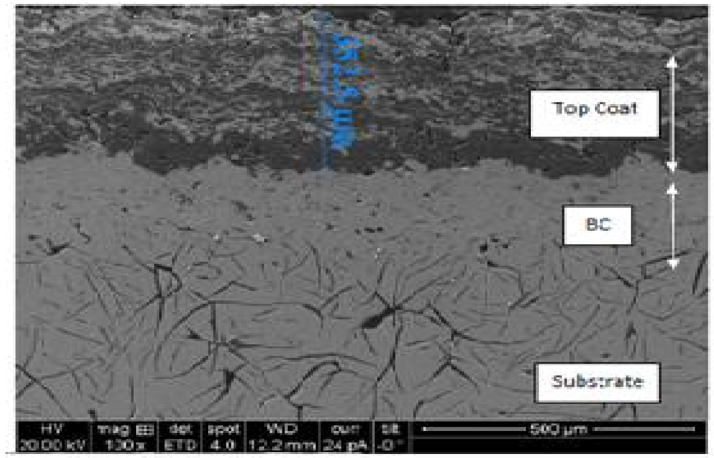

Fig-6 SEM image showing cross section of GCI 300μm top coat.

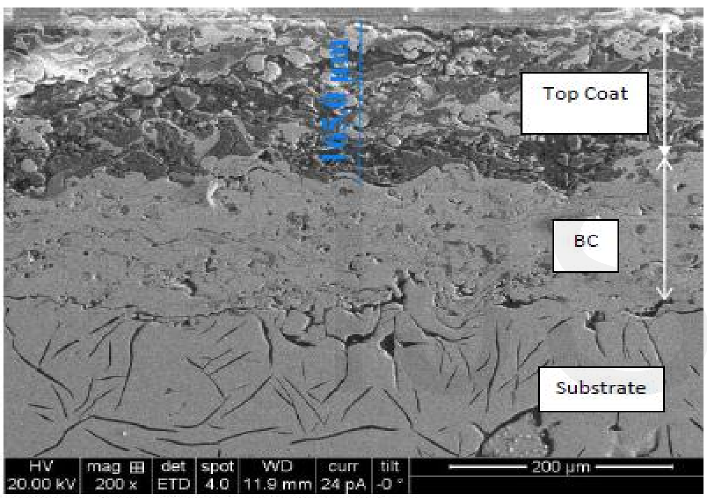

Fig-4 SEM image showing cross section of GCI 100μm top coat.

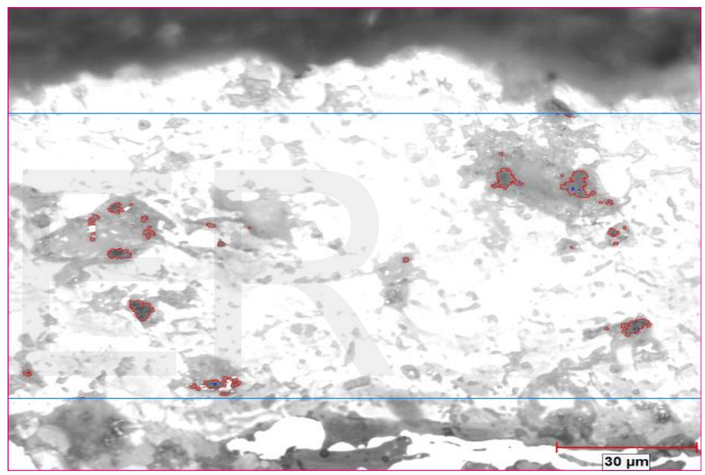

Fig-7 Porosity image analysis of Al6061- 300μm top coat.(1.0 %)

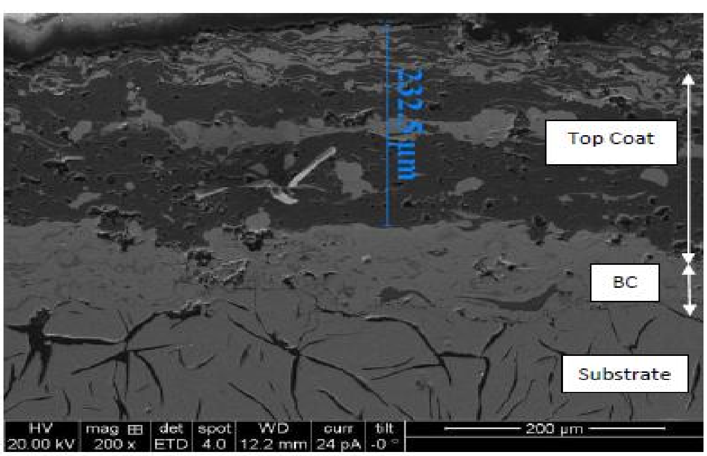

Fig-5 SEM image showing cross section of GCI 200μm top coat.

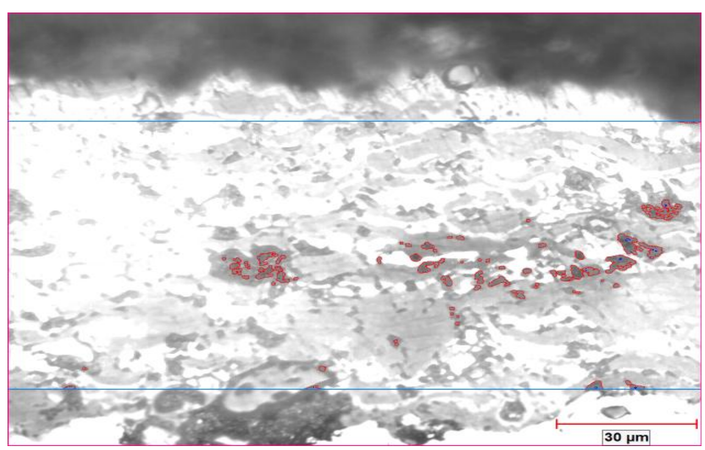

Fig-8 Porosity image analysis of Al6061- 200μm top coat.(1.41 %)

International Journal of Scientific & Engineering Research Volume 7, Issue 5, May-2016
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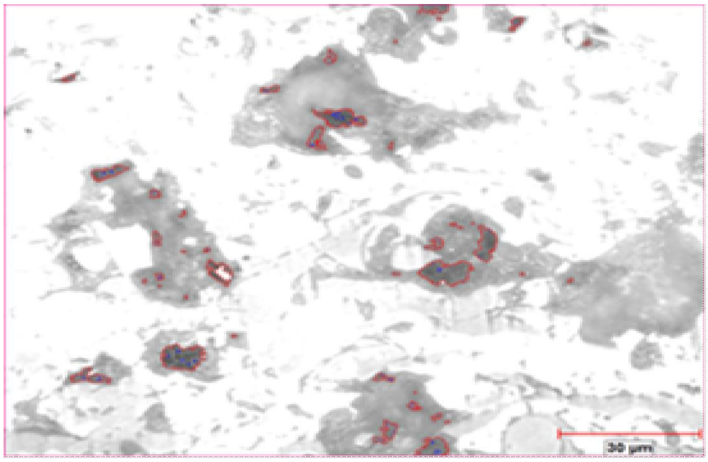


Fig-9 Porosity image study of Al6061- 100μm top coat.(1.58 %)

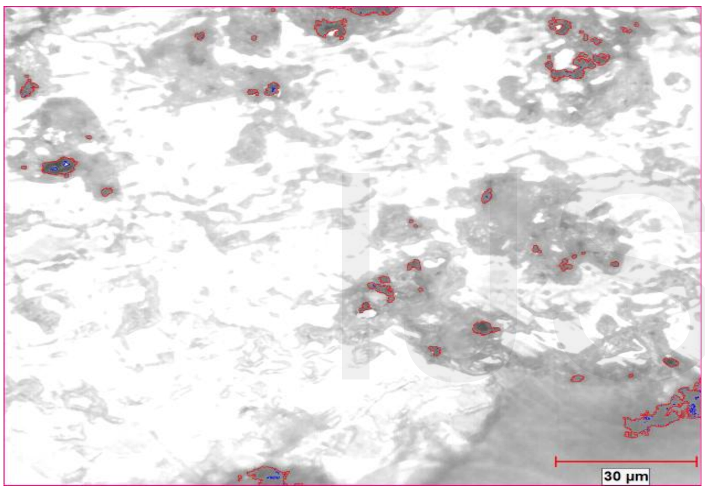


Fig-10 Porosity image study of GCI- 300μm top coat.(1.52 %)

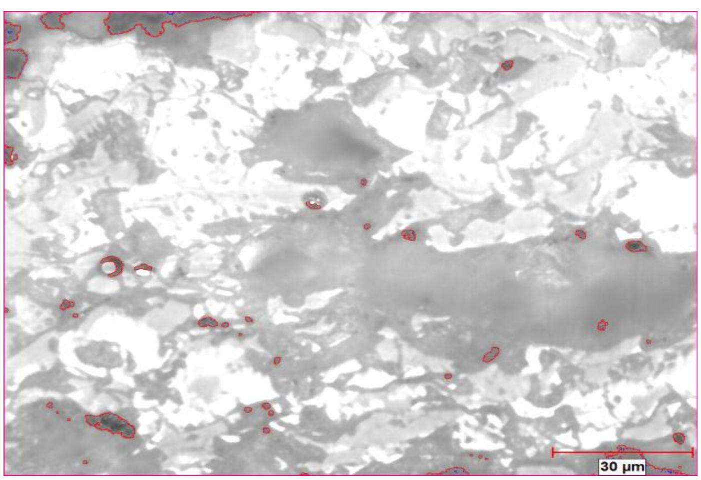


Fig-11 Porosity image study of GCI- 200μm top coat.(1.71%).

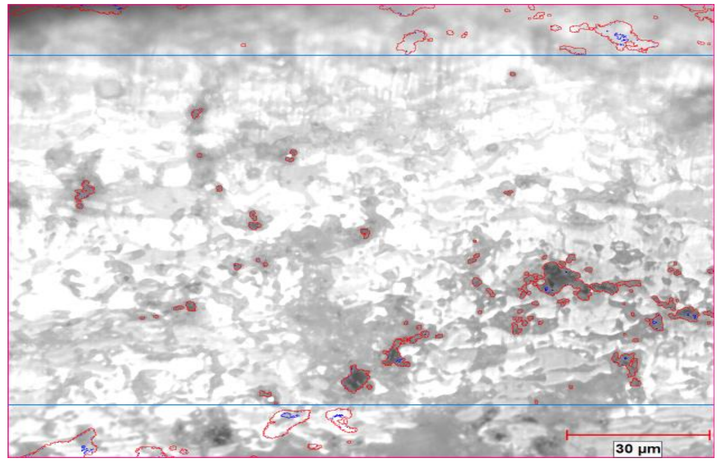
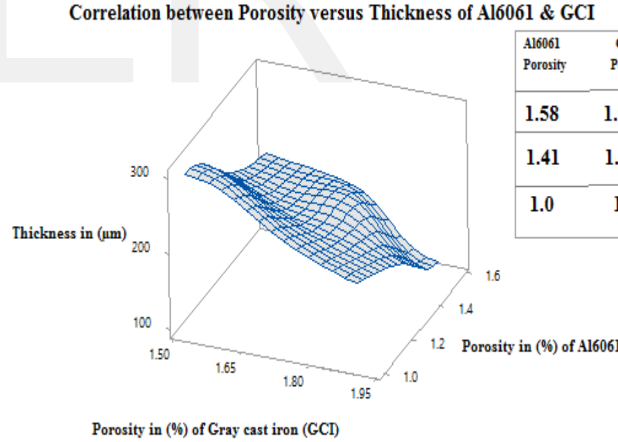


Fig-12 Porosity image study of GCI- 100μm top coat.(1.90 %).

In the porosity analysis an average of three readings was obtained. In the analysis it was found that, as the coating thickness increases porosity decreases in both the samples refer figs.7, 8, 9 Al6061, figs. 10, 11, 12 GCI. It was also found that porosity of GCI is marginally higher compare to Al6061 but remarkably the hardness of GCI is more due to relatively higher percentage of Tarzhenite phase.Graph 1 shows the correlation between porosity and thickness.

Correlation between Porosity versus Thickness of Al6061 & GCI



Al6061 Porosity	GCI Porosity
1.58	1.90
1.41	1.71
1.0	1.52

Graph -1 Porosity versus Thickness

3.3 Phase identification

In X-Ray Diffraction Investigations (XRD) a very unique Tarzhenite phase was identified whose weight percent is more compare to other phases.This phase formed due to solid state reaction during air Plasma coatings.Very few data are available on this rare phase.As per mineral data report this mineral exhibit high thermal expansion (α=11*10-6 K), excellent thermal insulation, low thermal conductivity (2.5-3w/mk) very high resistance to crack propogation, high fracture toughness.

International Journal of Scientific & Engineering Research Volume 7, Issue 5, May-2016
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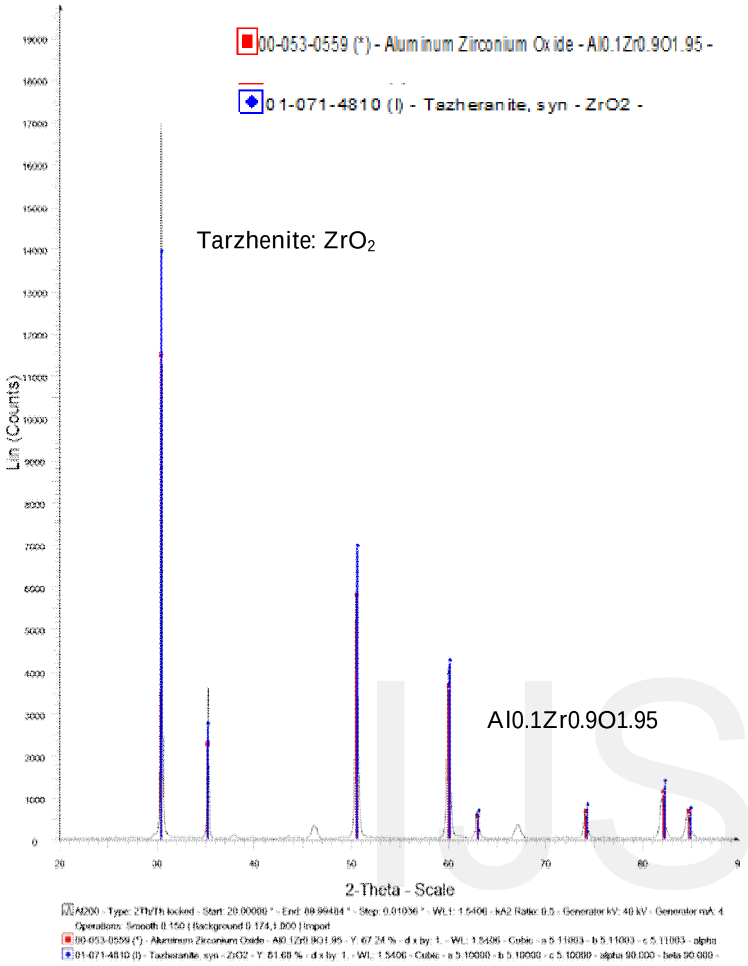
Graph 2 shows the XRD results investigated on the top coat of Al6061.A Similar phase was identified at the top coat of GCI.



Graph- 2 shows the XRD results for the top coat of Al6061

3.4 Hardness

The micro hardness evaluation is very sensitive to metallography polishing. In the Analysis it was found that the micro harness depends on the particle size, shape of the particles and density of the particles of the top coat.To ensure accurate readings an average of three readings considered at different locations, at the cross section of the samples. From the results it was also noticed that hardness is a function of top coat thickness, porosity and phases present on the top coat of the system. An average micro hardness value found 708.3HV0.1 & 616.8HV0.1 on GCI & Al6061 respectively.Though the porosity is marginally more in all the coating system of GCI compare to Al6061 but at the same time the weight percent of Tarzhenite phase was observed more compare to other phases in the add mixture of Al2O3+ZrO2.5CaO and can be attributed for high hardness of 300µm top .A general trend was percieved,as the top coat thickness increases the microhardness also increases in both the coating systems.

Fig-12 Hardness of top coat Al6061, 100 µm, an average value of 422.21HV0.1

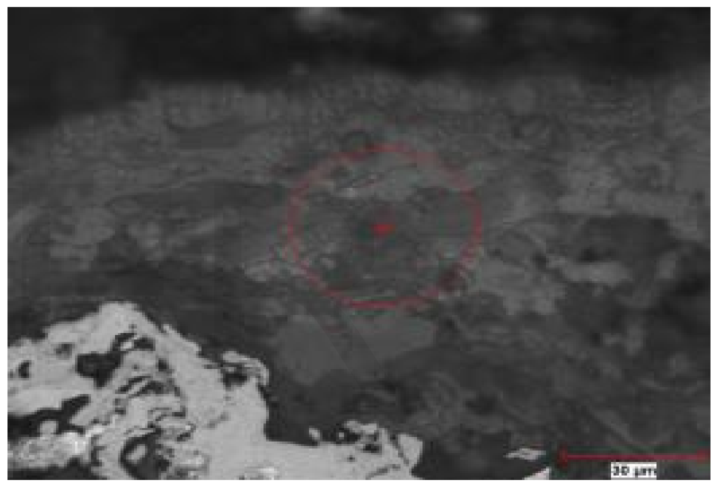


Fig-13 Hardness of top coat Al6061, 200 µm, an average value of 585HV0.1

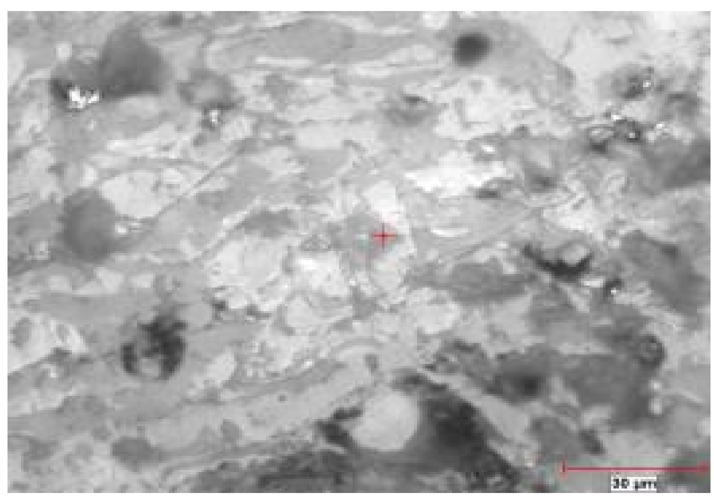


Fig-14 Hardness of top coat Al6061, 300 µm, an average value of 616.8HV0.1

International Journal of Scientific & Engineering Research Volume 7, Issue 5, May-2016
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Fig-15 Hardness of top coat GCI, 100 µm, an average value of 556.42HV0.1

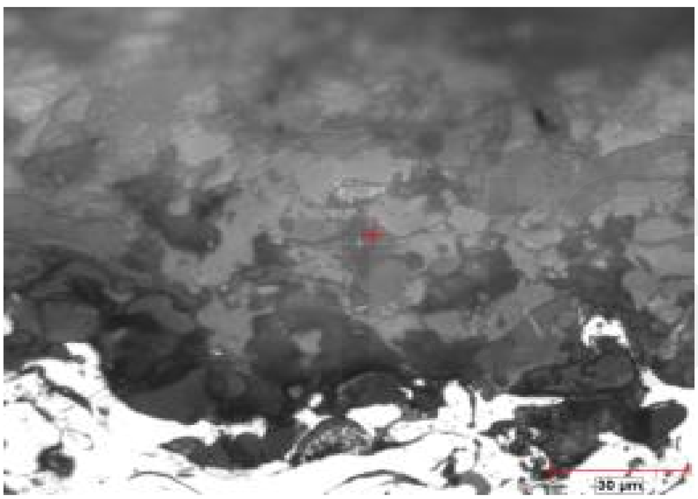


Fig-16 Hardness of top coat GCI, 200 µm, an average value of 668.98 HV0.1

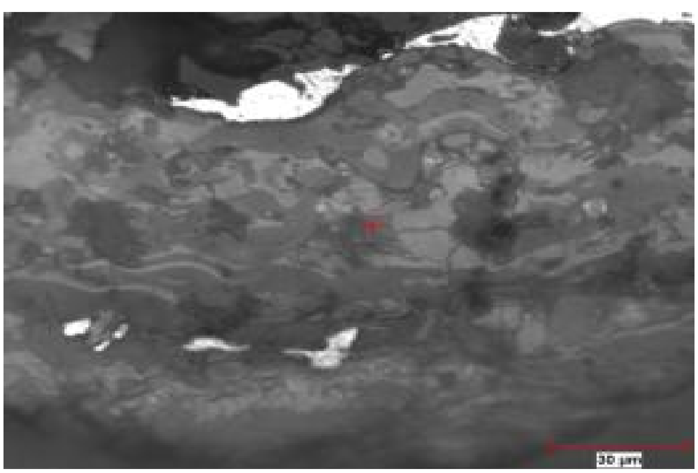
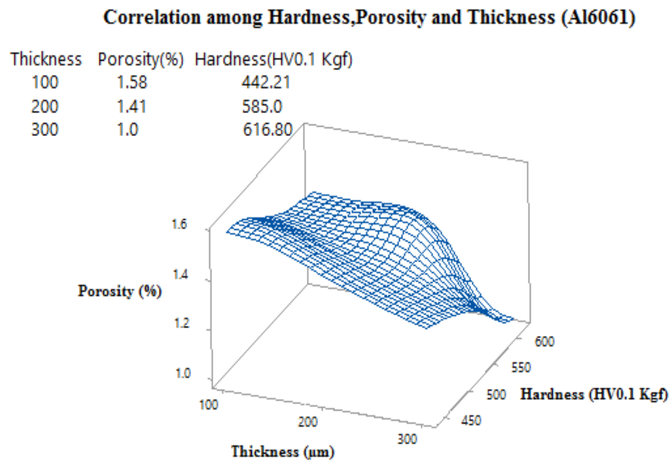
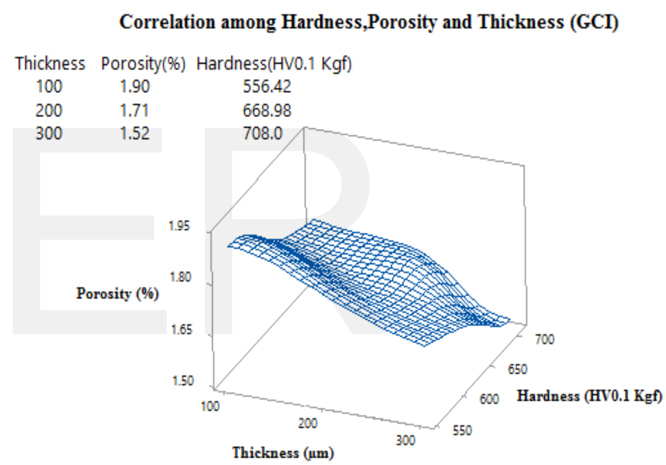


Fig-17 Hardness of top coat GCI, 300 µm, an average value of 708 HV0.1



Graph-3 Shows the variation of Micro Hardness, Porosity with Thickness on top coat of Al6061 substrate



Graph-4 Shows the variation of Micro Hardness, Porosity with Thickness on top coat of GCI substrate

4. Conclusions

Following are the conclusions made from the above investigations:

1. The selection of bond coat 1 Al25Fe7Cr5Ni and bond coat2 Al20330(Ni20Al) in case of Al6061 is recommended as there is minimal mismatch realized due to thermal coefficient of expansion.

2. The selection of top coat and (ZrO2.5CaO+Al203) and bond coat Fe38Ni10Al in case of Gray cast iron is strongly recommended since a very good adhesion realized at all the interfaces.

International Journal of Scientific & Engineering Research Volume 7, Issue 5, May-2016
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3. A very rare mineral Tarzhenite phase formed during solid state reaction and it's specific weight percent may alter the top coat microhardness as well as serve as lubricant with porosity less than 2%.

4. As the coating thicknes of the top coat increases, the micro hardness of the top coat also increases in all the coating systems.Exclusively the the microhardness of the top coat of GCI realized more 708 HV0.1 compare to 616.8HV0.1 in case of AL6061 for the same loading conditions.

5. Micro hardness is the strong function of spray parameters, spray conditions, local porosity, thickness, local density of the particles, shape of the particles and overall the metallography preparation of surface.

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