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USING OF METAL COATED DIAMOND BY POLYMERIC BINDER IN DESIGN OF SEGMENT USED IN NATURAL STONE SAWING PROCESS

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Original scientific paper

Performance of segment in the natural stone sawing process is decreased due to various reasons such as; non-uniform distribution of diamond grits, contact of diamond grits to each other's, segregation of uncoated diamond grits in metal matrix, wrongly selected type of metal powders and diamond grit size. The aim of this experimental work is to prevent the clustering of diamond grits in segment production and to improve the sawing performance of segment in terms of microstructure, density, hardness and wear properties by using metal coated diamond grits. Three types of diamond segments (A: Commercial segment, B: Diamond with coated segment, E: segment without diamond) were produced in different compositions by powder metallurgy (P/M) and each one of the segment sample was sintered at three different temperatures (800, 900, 1000 °C) holding fifteen minutes under vacuum by hot pressing method.

The highest hardness and wear resistance have been determined in B type sample sintered 900 ºC. The phases formed in the microstructures were analyzed using SEM, EDS techniques and mapping. Fractured surfaces and wear surface were examined by scanning electron microscopy and the fracture, wear mechanisms were evaluated.

Keywords: *Powder Metallurgy; Segment; Metal Coated Diamond; Microstructure; Mechanical Properties; Wear*

1 Introduction

It is reported that the natural stone processing industry has shown rapid development since 1930. Turkey has been influenced by this behavior, and many natural stone factories have been established in the last 30 years. Cutting disc (especially on the periphery of the steel disc in brazed diamond tool) consumption is the primary economic expenditure for natural stone processing [1]. Diamond reinforced metal matrix composites (MMCs) have been widely used for drilling, grinding, cutting and polishing in the natural stone, civil engineering, construction and ceramics industries due to the extreme hardness of diamond. Cutting tools can be produced using methods [2, 3] such as cold pressing and sintering, hot pressing, brazing and infiltration, hot isostatic pressing (HIP) and spark plasma sintering etc. Powder Metallurgy (PM) is the only viable method for manufacturing these tools because the solid state prevents excessive chemical interaction between the metal phase and the diamond, thereby avoiding graphitization [4]. Furthermore, friction decreases between powder and steel mold and cutting tools can be produced at lower temperature and under lower pressure. Cutting tool called segment is consisting of metal matrix and diamond. Basically, two types of metal powders are mixed and formed metal matrix. One is filler metal powders such as; Cu, Sn, brass and bronze [5]. These metals have lower chemical affinity to carbon and fill the pores formed during sintering. Second is the binder metal powders such as; Co, Ni, Fe, Ti, W and prealloyed powders (NEXT, KEEN etc.) [6]. These metals have higher chemical affinity to carbon. When diamond reinforced MMCs are heated, the metals attack the diamond surface and bonds are formed between the diamond surface and metal powder. These particular metals (Co, Ni, Fe, Ti, and W) have good wettability and chemical compatibility that holds the diamonds together and forms chip flow grooves via rapid wear during cutting. Also , the usage of which type powder as a binder metal into matrix depends on type of stone to be cut [7]. In addition to that metal carbides (MxCy; M=B, T, W etc.) particles can be defined as a third types of powder which can be added into metal matrix as wear controller [8, 9].

Addition of filler metal powders and MxCy particles modify the metallic binder phase characteristics, though the use of these additions is subordinated to the successful sintering of the tool material: total densification, good bonding between the diamond particles and the binder phase and chemical stability of the diamond during sintering

The use of diamond reinforced MMCs in the natural stone industry depends on the production conditions, working conditions and the texture of natural stones used. The parameters adopted for the production of diamond reinforced MMCs depends on (1) the bonding strength between the diamond grain and the matrix [10], (2) the wear rates of the diamond and the matrix [11] (3) the diamond quality (e.g., grain size, grain shape and strength) and (4) the diamond concentration in the composite [10, 12]. Oliveira et al. [13] stated that the mechanical properties (such as hardness and wear resistance) of diamond reinforced metal matrix composites mainly depend on the selection of matrix constituents. The mechanical behavior of the matrix can be varied by the addition of various alloying elements [14-24]. Bonding between the diamond and alloying elements occurs due to a reaction between the diamond surface and the surrounding metal matrix. The extent of this reaction depends upon the metal powder composition, particle size and distribution of the metals, processing temperature [14, 17] and time [9, 25].

Performance of segment in the natural stone sawing process is decreased due to various reasons such as; non-uniform distribution of diamond grits, contact of diamond grits to each other's, clustering of uncoated diamond grits in metal matrix, wrongly selected type of metal powders and diamond grit size. In all of these literatures given above, it is assumed that added diamond grits and metal carbides particles distributed in the metal matrix uniformly and homogeneously. However, this situation is never obtained since there are great differences in densities between metal powders (7.0-8.9 gm/cm3), diamond (3.51 gm/cm3) and metal carbides (for example; 15.63 gm/cm3 for WC). It is assumed that diamond grits have been distributed uniformly in metal powders in the serial production. Performance of segment produced by powder metallurgy (PM) is decreased due to non-uniform distribution of diamond grits in the segment.

Non-uniform distribution of diamond grits causes contact of diamond grits to each other's and clustering in metal matrix. Therefore, weak diamond –matrix bond takes place [24]. This problem is not solved by using Ti-coated diamond grits in segment production. Ti-coating thickness is around 1µm and TiC hard phase occurs on the surface of diamond grits. Touching or clustering of Ti-coated diamond in the metal matrix takes place due to same reason. If diamond grit is surrounded and bonded by metal powder using polymeric binder, metal coated diamond pellet is produced. The density of produced metal coated diamond pellets is higher than that of diamond and by this manner density differences are disappeared.

The aim of this experimental work is to prevent the touching or clustering of diamond grits in segment production and to improve the mechanical properties of segment in terms of hardness and wear properties by using metal coated diamond grits with polymeric binder.

2 Experimental method

In this study, the commercial segment is used as reference sample (sample A types), therefore the amount of constituents used in commercial segment production was not given here due to commercial secret. However, MX 1480 powder obtained from Eurotungstene (France) firm is used as matrix metal. MX 1480 powder is mixture of NEXT100 prealloyed and 20% Fe metal powders (NEXT100 powder is consisting of 29 Fe + 46 Cu + 25 Co in % weight). Powders size of MX 1480 is less than 100 µm. Bronze powder was used as filler metal and size is less than 50 µm. The ratio of MX1480 premixed powder to bronze is 4:1 in all produced segments. Elemental analysis of MX 1480 of prealloyed mixed powder was conducted by using Energy dispersive spectroscopy (EDS). Figure 1 shows the results of EDS analysis. Type E segments were produced without diamond powder (i.e. in the same time matrix of segment). Ti-Coated diamond powder was used for type B segment. The used materials for production of segment have been given in Table 1.

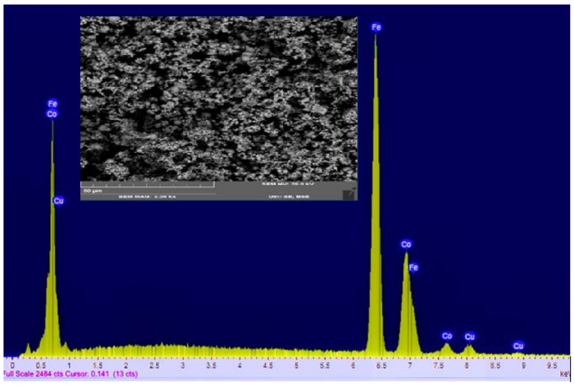

Figure 1. EDS analysis of Pre-alloyed mixed powder

Grit size of diamond is 40/50 mesh, and 20 concentiration (where a concentration of 100% diamond grits was designated as 4.4 carat/cm3) of Ti-coated diamond was used. For type of segment B, 20 concentration of Ti-coated diamond was coated with metal mixture (Co+bronze) by polymeric binder.

Diamond pellets were produced by Elementsix firm. Elemental mapping of diamond pellets was applied by using EDS. Figure 2 shows the elemental mapping of diamond pellet. Type B segments were consisted of 50% wt. matrix metal and 50% wt diamond pellets.

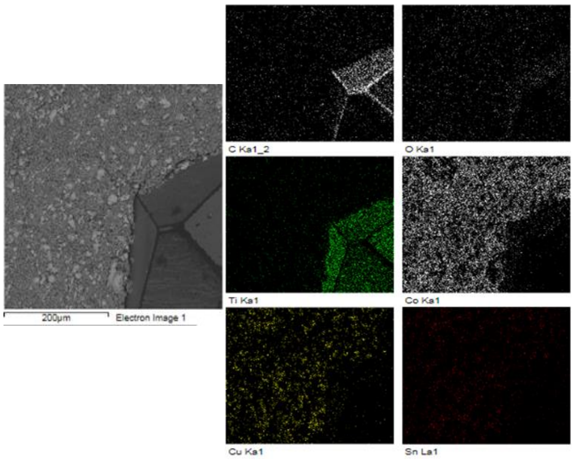

Figure 2. Elemental mapping of metal coated diamond

Table 1. Materials for segment production and sintering temperature.

Segment	Matrix		Diamond		Sintering Tem. (°C)
A	MX 1480 Pre alloyed mixed powder	Bronze (85/15 Cu-Sn)	20 Conc. diamond	-	800 900 1000
B	MX 1480 Pre alloyed mixed powder	Bronze (85/15 Cu-Sn)	20 Conc. diamond	20 Con. Metal mixture coated diamond by polymeric binder	800 900 1000
E	MX 1480 Pre alloyed mixed powder	Bronze (85/15 Cu-Sn)	- - -	- - -	800 900 1000

The production conditions (powder mixing time, heating- cooling rates, diamond concentration, hot pressing, and lubricant) of the commercial segment are the same as that of the produced segments in the current study. The performance of the commercial segment that was prepared by hot-pressing was analyzed in a similar manner.

The procedure below was used to synthesize segments (A, B and E) were blended for 45 min in a T_2F Turbula mixer, and alcohol with 2 wt% glycerin was added before blending to obtain a uniform and homogenous mixture. For each segment, the mixture was placed in carbon molds with dimensions equaling the commercial segment (24 x 10 x 8 mm). After setting the mold, the powder mixture was cold compacted under 35 MPa, and the green product in the mold was placed in a sintering machine. The hot zone was evacuated to remove air from the chamber, and sintering then was conducted using the hot press machine (Dimnet Sinter Machine) under vacuum. The glycerin was heated up to 500°C and held for 100 sec, and a brown product was produced and heated up to the sintering temperature. After brown product was obtained at of 500°C, the segments were heated to the selected sintering temperatures (800, 900 and 1000°C) under a compression load of 25 MPa and cooled in the sintering machine. The total sintering time (heating and cooling) was held between 12 to 14.5 min depending on the sintering temperature for each composite sample. Figure 3 shows the applied sintering regime. The sintering temperature must be maintained below 1150ºC to keep the diamond from reverting to graphite and the tool from losing its cutting capability [26].

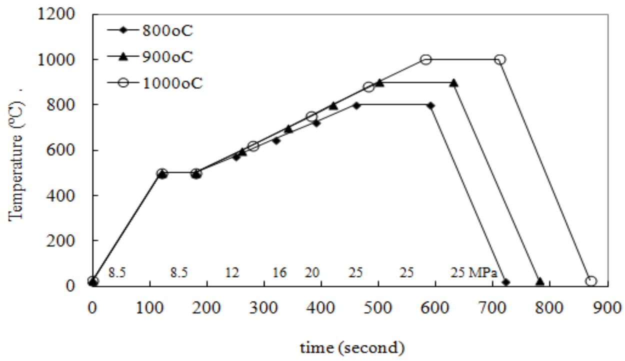

Figure 3. Applied sintering procedure to the segment

3 Results and discussion

In order to observe the distribution of diamond pellets in the metal matrix during the sintering process, pre-experimental study which a sample was sintered by using only diamond pellets was conducted. Figure 4 shows the behavior of diamond pellets during the sintering. Necking occurred between diamond pellets due to diffusion of elements and when the sintering temperature is increased, diffusion will be increased and necking process will be thickening. By this way, strong metallurgical bond will be taken place between matrix and diamond pellets. Also, it was measured the metal coating thickness as around 1.6 mm and in the same time it equals to the distance between two diamond.

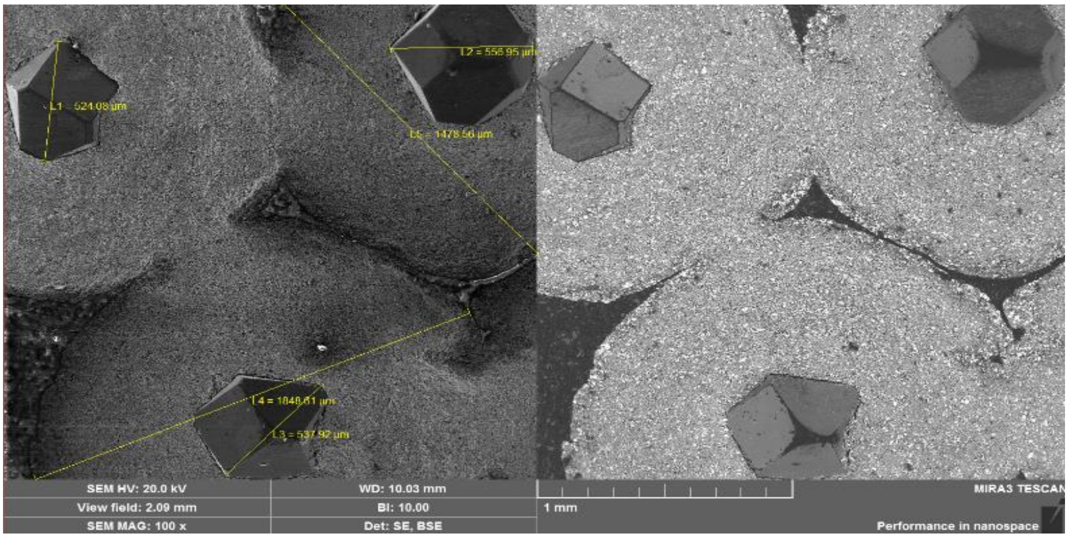

Figure 4. Metal coating thickness and necking between pellets due to diffusion of metals.

3.1 Density of segment

The experimental densities were measured with Archimedes' balance (using the AD-1653 specific gravity measuring kit) according to ASTM B311-92 standard. The densities of the segment were given in Figure 5. For E type segment which is the matrix of the segment, it is noted that as the sintering temperature increases from 800 ºC to 900 ºC, the densities of the produced segments increases. Then, densities of the segments decrease at the sintering temperature of 1000 ºC. Similar tendency was seen for A and B type segments. E type segments have higher density than A and B type segments for all temperatures due to fact that the density of diamond,

3.5 g/cm^3 is lower than that of metal powders and the presence of diamond grits increases the porosity in the segments during the sintering process. By the way, densities of A and B type segments decreases. The lowest density was obtained at 1000 ºC temperature due to increasing porosity in the all segments. B type segments have higher densities than A type segments for all temperatures. Because metal (Co+bronze) coated diamond increases the bonding between metal and diamond and decreases the porosity in the microstructure. Densification of the segment B is better than that of the segment A. Temperature of 900 ºC is suitable for sintering process for segment production.

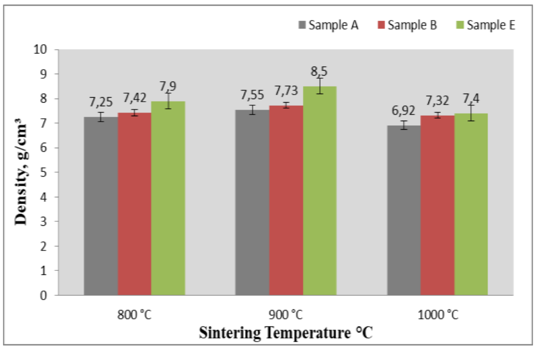

Figure 5. Density values of segments sintered at different temperatures.

3.2 Hardness

In order to determine the surface hardness of the segments, three segments were used for each type of segment and hardness test was conducted five times from each sample. Average values of fifteen measurements for each type of segment were given. Surface hardness test was carried out applying 100 kgf loads in terms of Brinell hardness. Figure 6 shows the relationship between hardness and sintering temperature. Surface hardness of each type of segment increases with increasing sintering temperature excluding segments sintered temperature of 1000 °C. Produced segments with diamond (Type A and B) have higher surface hardness values than segment without diamond (Type E) because of dispersion effect of diamond in the matrix.

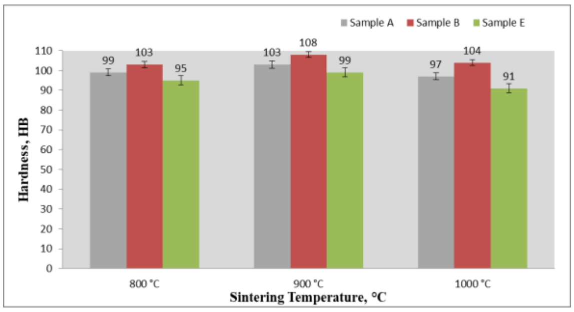

Figure 6. Effect of sintering temperature on the surface hardness of the segment

Presence of diamond grits hinders the motion of dislocation in the matrix (i.e. interaction mechanism between dislocation and dispersed phase). Type B segments have higher surface hardness value than Type A segment for all sintering temperature due to Co+Bronze coating with polymeric binder on surface of the diamond grits. Metal coating with polymeric binder creates stronger bond between diamond and coating metal (Co+bronze). It can be say that bond strength can be improved more and more if diamond grits are coated only Co metal since Co element has higher affinity to diamond. For sintering temperature of 1000 °C, surface hardness of each type of sample decreases [27-29]. It is attributed that grain growth mechanism occurred in the metal matrix for all type of segment and also strength of binding at the interface decreases due to graphitization of diamond for Type A segment.

Figure 7 shows fracture surface of two segments. One is Type B segment sintered at 1000 °C (on the left) and there is no any change of diamond color (yellow). Second one is Type A sintered at 1000 °C (on the right) and there is a change of diamond color from yellow to black due to catalytic effect of Fe. This is evidence of the structural decomposition of diamond to graphite and metal coating prevents the contact of Fe to diamond in the metal matrix.

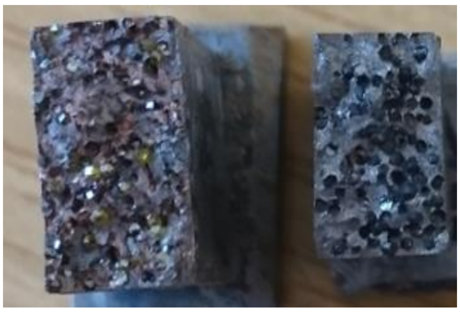

Figure 7. Changing of diamond color at sintering temperature of 1000 °C. Type B segment (on the left) and type A segment (on the right)

3.3 Wear test

Wear test was conducted three times for each type of segment in order to determine the wear loss of the segments. Average values of wear losses were given. PLINT multipurpose friction machine was used for wear

tests to evaluate the wear characteristics of the segments. Wear test were applied with speed of 350 rpm, 500 m sliding distance and under three different load of 72, 87 and 102 N at room temperature. Segments were cleaned with alcohol before and after wear test and wear amount were measured by using four digit electronic balances in terms of weight. Figure 8 and 9 shows the effect of load and sintering temperature on wear amount, respectively. As it is seen in Figure 8, when the load increases, wear amount increases for each type of segment. The highest wear amount
sdo was calculated from Type E segment because diamond grits were not added into Type E segment. Addition of diamond highly increases wear resistance of segment. The lowest wear losses were measured from Type B segment since metal coating (Co + bronze) decreases wear amount or increases wear resistance. Metal coating prevents accumulation and touching of diamond grits each other's. Distribution of diamond pellets is more homogeneous and uniform in the metal matrix. By this way, performance of segment improves against to wear. In addition to that metal coating improves the binding of diamond to coated metal.

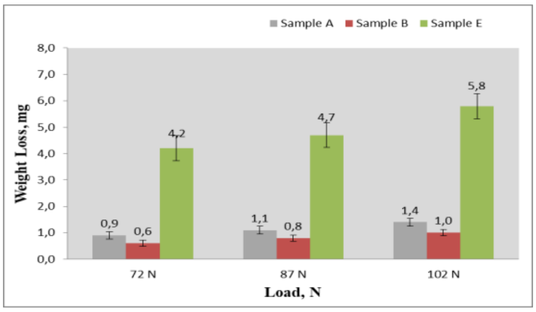

Figure 8. Effect of applied load on the wear loss of segments sintered at 900 °C

The effect of sintering temperature on wear loss of the segments is given in Figure 9. As it is seen in Figure 9, usage of metal coated diamond improves the wear resistance of the segment sintered at the same temperatures. Increasing sintering temperature decreases

in the wear loss except sintering at 1000 ºC. Type E segment produced without diamond has the highest wear loss for all sintering temperature. The lowest wear loss was obtained from the Type B segment sintered at 900 ºC. For Type B segment produced at 1000 ºC, it is observed that grains in the metal matrix grow and strength of segment decreases. Therefore, the wear resistance of the segment decreases or the weight loss increases. For Type A segment, the weight loss decreases as the sintering temperature increases and then increases. Increasing of weight loss is due to structural decomposition of diamond and grain growth of metal matrix.

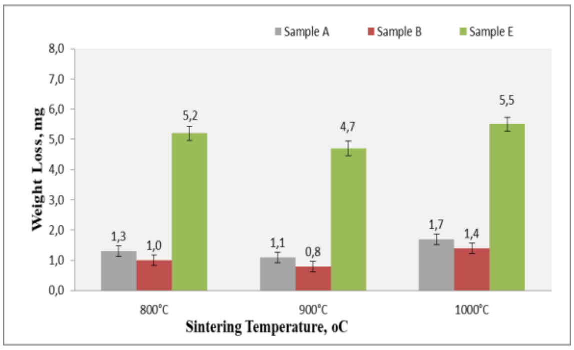

Figure 9. Effect of sintering temperature on the wear loss under applied load of 87 N.

3.4 SEM and EDS Studies of Worn Surface

In order to determine the wear mechanism on the surfaces of the segments, SEM analyses were performed by Mira3XMU-Tescan. Figure 10 shows the worn surface of the Type E segments (without diamond). Main mechanism is adhesive type wear mechanism. There is evidences on the surface like that some part of metal removed from surface of the segment by applied load and the applied load create a shear load to surface and some sort of metal removes from the surface. Removed metal from surface welds to counterpart or to surface of the metal and the metal surface becomes so rough. Worn surfaces of Type E segments sintered at 800 and 1000 ºC have more rough than that of sintered at 900 ºC. It can be concluded that suitable sintering temperature is 900 ºC.

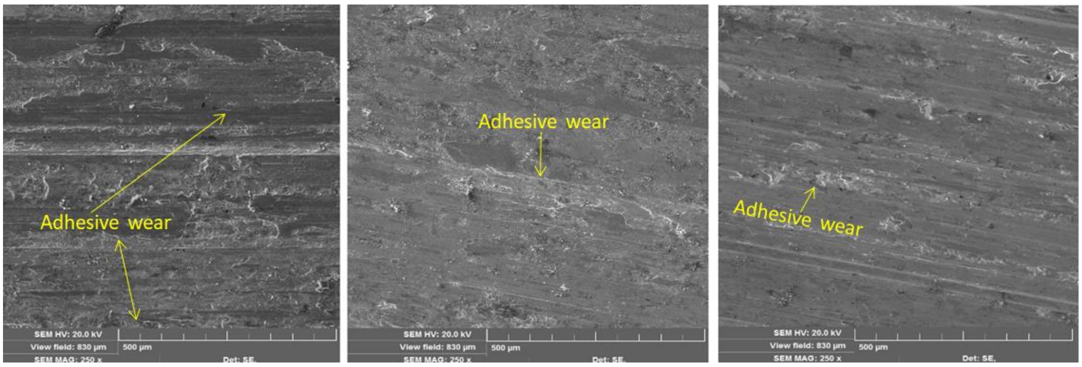

Figure 10. Worn surfaces of Type E samples under load of 87 N; sintered at a) 800 ºC, b)900 ºC, c)1000 ºC

Figure 11 shows the worn surfaces of Type A segments sintered 1000 ºC under load of 87 N. Abrasive wear mechanism is shown due to presence of diamond (Figure 11a). It is understanding that three body wear mechanism occurs because hard particles (such as diamond and oxide particles) have broken off from segment and counterpart (hard steel) and placed between segment and counterpart. These hard particles have created grooves line on the surface of the segment. It is contributed that leakage of diamond and breaking off diamond from metal matrix are shown due to less retention of diamond by metal matrix (Figure 11b). However, adhesive wear mechanism is shown some places where the hard particle does not present on the segment surface (Figure 11c).

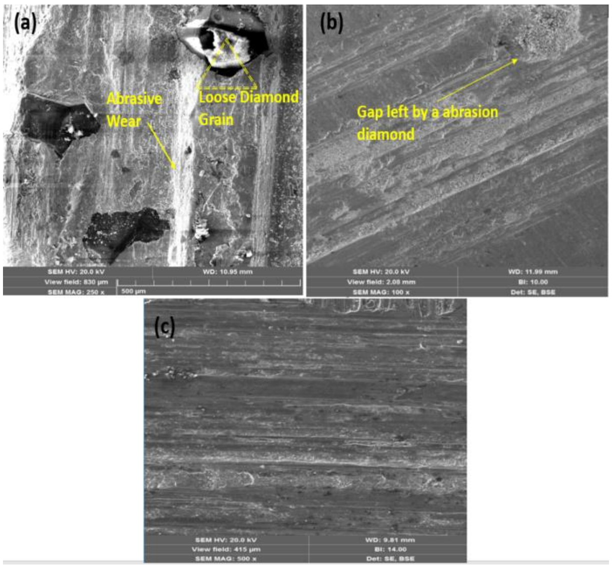

Figure 11. Worn surfaces of Type A samples under load of 87 N; sintered at a) 800 ºC, b)900 ºC, c)1000 ºC

Figure 12 shows the worn surfaces of Type B segments sintered 1000 °C under load of 87 N. Abrasive wear is the dominant mechanism but also, adhesive wear is shown somewhere.

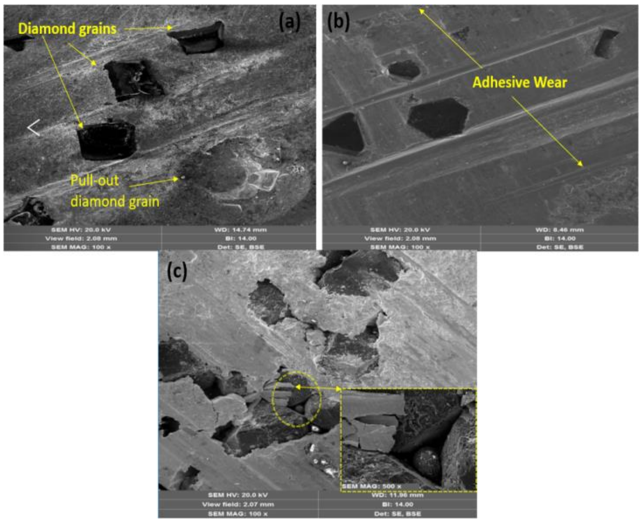

Figure 12. Worn surfaces of Type B samples under load of 87 N; sintered at a) 800 ºC, b)900 ºC, c)1000 ºC

Figure 13 shows the elemental mapping of worn surface of B segment sintered at 900 ºC under the load of 102 N. In this study, MX1480 prealloyed metal and bronze metal powders were used. As it is seen that used powders distributed uniformly in the matrix. Prealloyed powder is consisting of some alloy phases such as Co-Fe, Co-Cu, Fe-Cu or Co-Fe-Cu. These phases increase the hardness and wear resistance of metal matrix. Also, addition of diamond improves the mechanical properties (hardness and wear resistance) of segment. Cr and Ni metal powders were not added and it is understood that they come from the production of the MX1480 prealloyed metal powder. Metal oxides phases (especially Fe_xO_y) takes place during the wear test by increasing temperature and sintering of segment. Fe_xO_y phase is a brittle phase and increases the wear lost.

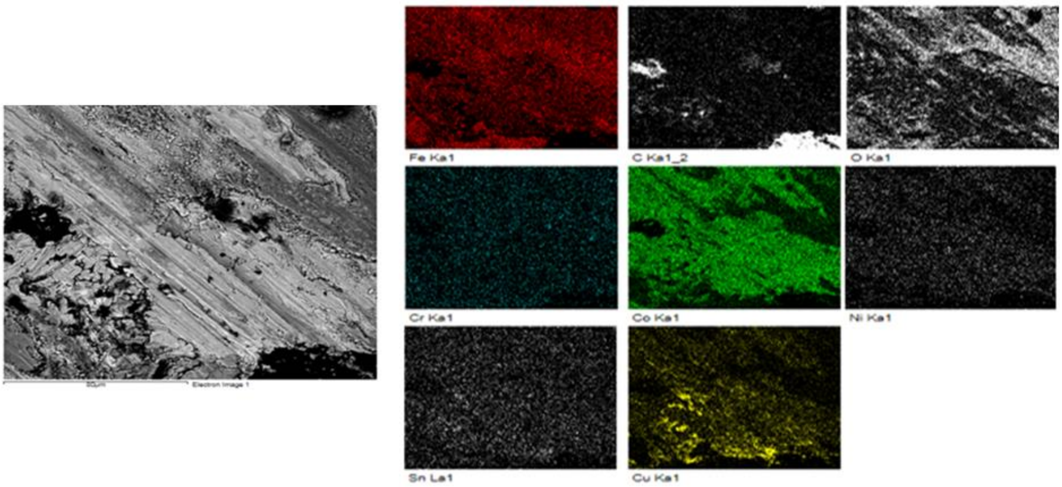

Figure 13. Elemental mapping of worn surface of Type B segment sintered at 900 ºC under load of 102 N

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3.5 SEM Images of Fracture Surfaces

The produced segments were broken down by using a clamp and a hammer. Figure 14 shows the fracture surface of the segments sintered at 900 ºC and 1000 ºC. Type E segment behaves as like a ductile material. As it is seen that fracture surface is rough and dark and also grain of particles and pores extended due to the plastic deformation (Figure 14a). Type A segment has brittle fracture surface since the surface is smooth and bright and shape of pores has not changed under load (Figure 14b). Brittle and ductile fractures are shown on the fracture surface of the Type B segment (Figure 14c). The left side of the image is ductile part and the right side of the segment is brittle part. Fe powder creates brittle phase as like Fe_xO_y but prealloyed metal (MX1480) and bronze powder gives ductility to segment. For Type B segment sintered at 1000 ºC, glassy fracture taken place since the graphitization occurs at high temperature (Figure 14d).

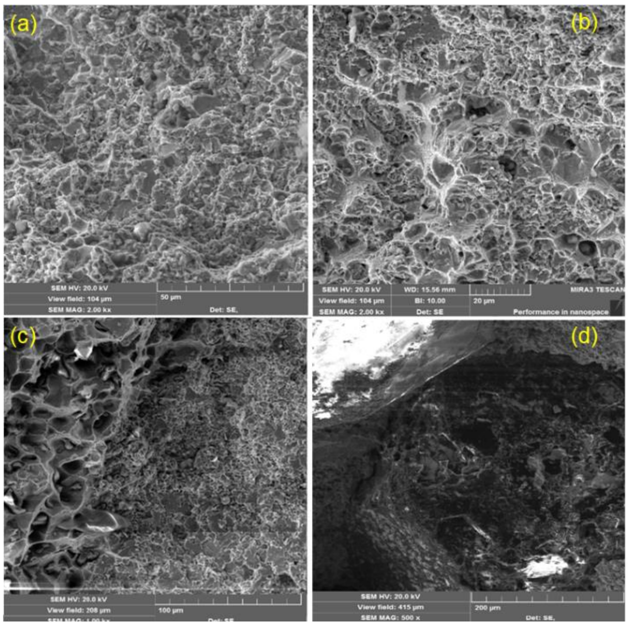

Figure 14. Fracture surface of the segments; a)E_{900} b)A_{900} c)B_{900} d)B_{1000}

4 Conclusions

In this study, new type segment (Type B), which is consisting of metal coated diamond grit surface by using polymeric binder, was produced by hot pressing sintering technique. The mechanical properties new type of segment compared with commercial segment (Type A) and following results were concluded;

- Using of metal coated diamond grit surface by polymeric binder solves the problem which is the non-uniform distributions of diamond grits in the segment production.
- The highest hardness was measured from Type B segment sintered at 900 ºC,. Increase in sintering temperature improves the mechanical properties. However, graphitization of diamond occurs due to catalytic effect of Fe element when the segment sintered at 1000 ºC,. Therefore, this temperature is not suitable for segment production. For all type of segments sintered at 1000 ºC,, the hardness values decreases.
- Wear resistance of the segment improved by using metal coated diamond by polymeric binder. The lowest weight lost was obtained from Type B segment sintered at 900 ºC,.
- While diamond reinforced segments (Type A and B) have abrasive wear mechanism mainly, the segments without diamond (Type E) have adhesive wear mechanism.
- The segment with metal coated diamond by using polymeric binder (Type B) have better mechanical properties than the commercial segment (Type A).

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