Extended Abstract

Characterization of metal alloys produced by PM using microwave technology

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Abstract

Diamond tool industry demands for new and more economic, competitive and environmental friendly fabrication processes. In this respect, one possible solution is using microwave hybrid sintering (MW) for the manufacture of diamond tool segments. Nonetheless, there is still few data available on MW of diamond segments.

Thus, the aim of this work is studying the effect of microwaves on the sintering behavior of the matrix and metal matrix composites (MMC) segments by MO and free sintering (FS) techniques, as a function of temperature, dwell time and green density. In addition, physical and mechanical properties of MW sintered segments were determined and compared to those obtained by conventional hot pressing (HP).

It was observed that microwave heating enhanced the densification process, thereby reducing the optimum sintering temperature between 90°C and 170°C (depending on the green density of the compacts) when compared to FS.

MMC segments sintered by MW under optimized conditions (green density of 57%, temperature of 822°C and dwell time of 5 min) showed values of flexural strength ($\sigma_R = 1039 \pm 83 \text{ MPa}$), Young modulus ($E = 178 \pm 5 \text{ GPa}$) and fracture toughness ($K_{IC} = 14.8 \pm 1.7 \text{ MPa.m}^{1/2}$) similar to those obtained by HP ($\sigma_R = 986 \pm 120 \text{ MPa}$; $E = 196 \pm 3 \text{ GPa}$; $K_{IC} = 15.8 \pm 1.5 \text{ MPa.m}^{1/2}$). Thus, future work should be focused on the evaluation of the cutting performance on ornamental stones.

Key-words: Diamond tools, Microwave hybrid sintering, Hot pressing, Flexural strength, Two-parameter Weibull distribution, Fracture toughness

1. Introduction

The ornamental processing involving operations such as sawing, drilling, grinding and polishing is nowadays a well established industry, whose development is associated with the availability of synthetic diamond tools. These tools are also used for machining of construction materials, glass and ceramics as well as for oil/gas drilling [1]. Diamond tools for cutting ornamental stone are composed by diamond products that can be, or not, brazed or welded by laser to a metallic support. Among these, diamond segments, are metal-matrix composite materials (MMC) containing synthetic diamonds, typically 5-10v% [2].

Diamond segments commercially available in the market are produced through powder metallurgy (PM) route [2]. PM is a process whereby a material powder is compacted as a green body and sintered to a
net shape at elevated temperatures below its melting temperature, in a controlled atmosphere to bond the particles metallurgically [3]. The production route for impregnated diamond segments involves a number of PM operations, such as, powder mixing, granulation, cold die pressing and a consolidation stage which is referred as sintering, which is a thermal treatment of a compact for the purpose of increasing its strength by bonding together of the particles. Impregnated diamond segments are typically produced by hot pressing, with a minority being processed by FS (or pressureless sintering).

The hot pressing process consists of a simultaneous application of heat and pressure so that a product nearly free from residual porosity is obtained [4]. Compared to the conventional cold pressing/sintering PM route, hot pressing requires merely 2–3 min hold at markedly lower temperature, but under a compressive stress, to reach higher density level [2]. Hot pressing of diamond-impregnated segments is generally realized in high-resistance graphite moulds by passing electrical current directly through the mould. Nevertheless, this sintering process involves high energy consumption. Thus, there are challenging demands from the diamond tool industry for more economical production processes combining a reduction in energy consumption with better physical and mechanical properties. This is where the microwave technology is being regarded as advantageous.

Microwaves are a form of electromagnetic radiation with frequencies ranging from 300MHz to 300 GHz. Microwave heating is a process in which the materials couple with microwaves, absorbing the electromagnetic radiation volumetrically, thereby transforming it into heat through their interaction with materials. Thus, microwave heating entails the conversion of electromagnetic energy to heat unlike in conventional processes where heat is transferred to the surface of the material by conduction, convection or radiation. Microwave heating is advantageous due to enhanced diffusion processes, reduced energy consumption, very rapid heating rates and thence reduced processing times, decreased sintering temperatures, improved physical and mechanical properties and lower environmental hazards [5].

Microwave heating in materials is closely related to their dielectric and magnetic properties. Materials can be categorized into three main groups: transparent, opaque and absorbers. Metal are typically opaque (conductors) to microwaves, i.e., microwaves are reflected and cannot penetrate. However, powdered metals were found to be effectively and efficiently sintered at 2,45 GHz even though the skin depth in the bulk metals is very low (few microns) and thence very little penetration of microwaves takes place.

A combined action of microwave heating and infra-red heat source (termed microwave hybrid heating) can be utilized to realize rapid sintering from both inside and outside of the powder particles [6]. The hybrid heating system will heat the sample more readily at low temperatures and at high temperatures will

Figure 1 - Temperature profile within the sample in: (a) conventional heating, (b) microwave heating and (c) microwave hybrid heating. Courtesy of [5]
flatten out the temperature profile inside the sample body (Figure 1). This can be achieved using a material, which is called susceptor, which has high dielectric losses at low temperatures (i.e. room temperature), such as SiC.

Recent exploratory studies performed at Laboratório Nacional de Energia e Geologia (Lisbon, Portugal) showed that MW of impregnated diamond segments was achieved, at temperatures around 900°C with an overall thermal cycle time of 20 min, reducing conventional sintering temperature by nearly 80°C [7]. Nevertheless, there is still scarce data available on MW of impregnated diamond segments [8]. However, there is some information regarding microwave sintering of metals, such as, Fe, Co, Cu, Sn, Ti and their alloys [9] [10] [11] [12], usually used as binders in impregnated diamond segments.

Thus, this work aims at studying the viability of MW technology applied to diamond tools manufacture. For this purpose, the effect of microwaves on the sintering behavior of the matrix segments by MO and FS techniques was evaluated, as a function of temperature, dwell time and green density. In addition, physical and mechanical properties of MW sintered matrix and MMC segments were determined and compared to those obtained by conventional HP.

2. Experimental procedure

2.1. Materials

Matrix powders, cobalite CNF ($d_{50} = 11 \mu m$), ultrafine Co ($d_{50} = 6 \mu m$ ), iron phosphate ($d_{50} = 6 \mu m$), tin bronze ($d_{50} = 36 \mu m$) and tungsten carbide ($d_{50} = 5 \mu m$), were mixed in a turbula mixer. MMC green bodies containing 5 v% diamond ($d_{50} = 360 \mu m$) were also prepared. The mixed powders were uniaxially pressed into parallelepipedic-shaped compacts in steel mould (23 mm x 10 mm) at pressures of 160 MPa, 350 MPa and 610 MPa, in order to obtain compacts having the green density of 57%, 67% and 77%.

2.2. Sintering of segments

Hot-pressing cycles were performed using a Vulcan 70 SV furnace (70 kW) developed by IDEA (Piacenza, Italy) in a controlled atmosphere ($Ar / 5v% H_2$). Temperature was monitored using an optical pyrometer. Matrix and MMC segments were sintered at 850°C with a dwell time of 3 min, applying an external pressure of 35 MPa.

The microwave furnace used in this study was fabricated by Microwave Research & Applications (Illinois, USA). The multimode microwave furnace consists of a 2.45 GHz microwave generator with an adjustable power output (up to 1 kW). Temperature measurements were done by a Pt-sheathed Type-S thermocouple (Pt-Pt/10%Rh, $T_{\text{max}} \approx 1700^\circ$C) placed close to segments surface (around 2 mm). The MW set up inside the furnace cavity is shown in Figure 2. At first, the green segments were placed in the center of the thermal insulation pod (Figure 2 c)), and were surrounded by two SiC susceptors (Figure 2 a)). Then, segments were confined in a controlled atmosphere ($Ar / 7v% H_2$) inside a quartz tube (inner diameter of 17 mm, length of 200 mm; Figure 2 d)). The protection gas was inflated into quartz tube through the Type-S thermocouple (Figure 2 e)) at a flow rate of $2 L\text{min}^{-1}$. MW cycles were performed at temperatures in the range of 622°C−922°C and dwell times from 3 min to 60 min.

The conventional FS was conducted in an electric horizontal tubular furnace (6.5 kW) developed by Termolab (Águeda, Portugal).
The sintering cycles were performed in a controlled atmosphere of flowing Ar. The temperature was read through a Type-K thermocouple (NiAl-NiCr; $T_{\text{max}} = 1260^\circ\text{C}$) placed closed to the segments inside the alumina chamber. In order to prevent surface oxidation, segments were placed between graphite plates. Matrix segments were sintered conventionally in a range of temperatures from 767$^\circ\text{C}$ to 967$^\circ\text{C}$.

In order to compare the results obtained by MO and FS cycles, it was necessary to assess the temperature measurement deviation between Type-S and Type-K thermocouples at a given reference temperature ($T^\circ$). Hence, temperatures measured by Type-S ($T_{\text{TC-S}}$) and Type-K ($T_{\text{TC-K}}$) thermocouples had to be corrected according to Equations (1) and (2):

\begin{align}
T_{\text{TC-S}} &= T_{\text{TC-S}} - 28^\circ\text{C} \\
T_{\text{TC-K}} &= T_{\text{TC-K}} + 17^\circ\text{C}
\end{align}

2.3. Physical and mechanical characterization of sintered segments

MMC sintered segments’ surface was cleaned using a wire brush disc. Matrix segments were subjected to metallographic preparation involving grinding and polishing using series of diamond suspension ($15 \mu\text{m}$, $6 \mu\text{m}$ and $3 \mu\text{m}$) and final cloth polishing using a $0.5 \mu\text{m}$ SiO$_2$ suspension. Matrix segments were etched, using 2% Nital solution for 30s, for SEM-EDS analysis.

The densities were measured by the Archimedes method ($\rho$), in the case of MW and FS segments, and by helium gas picnometry ($\rho_{\text{H}}$), in the case of HP segments. The relative density ($\%\rho$) was defined as the ratio of the density of sintered segments to the density of the segments sintered by HP. Thus, the porosity of sintered segments was estimated by Equation (3).

\begin{align}
\text{Porosity} = 1 - \%\rho
\end{align}

Determination of the dynamic Young’s modulus ($E$) and shear modulus ($G$) were carried out using RFDA System 23 (Belgium) equipment, developed by IMCE, in flexural and torsional vibration modes, respectively, according to ASTM E1876-01 (2004) standard. Vickers hardness ($HV$) was measured using the hardness tester Wolpert 432-SVD with an applied load of 1$kg$ for 10 $s$, according to ISO 6507-1 (2005) standard.

Flexural strength ($\sigma_R$) was evaluated through three point flexural tensile tests based on ISO 3327 (2009) standard. Test was conducted in an Instron 3369 machine at crosshead speeds of 1.0 $mm/min$ for MW segments and of 1.5 $mm/min$ for HP segments. Weibull modulus ($m$) was estimated using for the two-parameter Weibull distribution by maximum likelihood estimation method according to ASTM C1239 (2013) standard.

The fractured surfaces were observed both in an Olympus SZH microscope and a...
Philips FEG XL30 scanning electron microscope. The fracture origin’s depth (a or 2a) and width (2c) were measured using image analysis software AnalySIS developed by Olympus Soft Imaging GmbH. Fracture toughness ($K_{IC}$) was estimated by fractography according to ASTM C1322 (2005) standard.

3. Results and discussion

3.1. Optimization of MW thermal cycle

**Effect of microwaves on the densification behavior of segments**

Figure 3 shows the densification curves obtained for matrix segments sintered by MW (MO-57%) and FS (FS-57%) from compacts having a relative green density of 57%.

![Figure 3 - Densification curves for MO-57% and FS-57% series. (Dwell time of 5 min).](image)

It is observed that the profiles of both curves are similar. However, MO-57% curve is shifted to temperature as low as about 100 °C when compared to FS-57% curve. Furthermore, a sintering plateau is seen in the case of MW sintered compacts unlike in the case of the FS-57% curve (not seen up to 967°C). For instance, at 767°C, MW segments showed higher bulk density (93%) than that obtained by FS (63%). Assuming that the optimum sintering temperature corresponds to a densification of 95%, it can be seen that it is 822°C for the MO-57% series, whereas for the FS-57% series is around 917 °C. Thus, microwave effect on the densification of segments with a green density of 57% can be quantified with a reduction in sintering temperature of around 90 °C.

Figure 4 shows the densification curves for matrix segments sintered by MW (MO-67%) and FS (FS-67%) from compacts with a green density of 67%. Under these conditions, it is evident that the optimum sintering temperature for MO-67% series is around 772 °C (92%), while for the FS-67% series was 917 °C (95%). Thus, it is observed that MW technique may reduce optimum sintering temperature up to 140 °C when compared to FS technique, under the conditions investigated.

![Figure 4 - Densification curves for MO-67% and FS-67% series. (Dwell time of 5 min).](image)

Figure 5 shows the densification curves for matrix segments sintered by MW (MO-77%) and FS (FS-77%) from compacts with a green density of 77%. It was also observed a significant effect of microwaves on the densification behavior of matrix segments from 77% series. In this case, the optimum sintering temperature for MW segments is close to 747 °C (93%), whereas for the FS-77% Series it is 917°C (94%), i.e., a temperature reduction of 170°C.

![Figure 5 - Densification curves for MO-77% and FS-77% series. (Dwell time of 5 min).](image)
Green density effect on the densification behavior of segments produced by MO

Figure 6 shows the effect of green density on the densification behavior of segments produced by MW. Up to 747 °C, there is a direct relationship between green density and final density of the sintered segments, i.e., the higher the green density, the higher the final density. However, above 747 °C, two distinct behaviors were observed. While for the MO-57% series, the degree of densification of the segments continued to increase with increasing temperature, in the cases of MO-67% and MO-77%, a sudden decrease in the final density was recorded.

Such decrease in density in MO-67% and MO-77% series, above temperatures of 797 °C and 772 °C, respectively, is not due to an increase in residual porosity, but rather, to a non uniform densification. An identical phenomenon was described by Takayama et al [13]. As temperature increases, the diffusion rate also increases and hence the necks between particles grow faster. Above a certain temperature, the growth of the necks is such that the material starts to behave as a bulk metal, suppressing the penetration of microwaves (“shield effect”). Consequently, segments continue to densify at the surface, whilst their interior remains porous. In some cases, the surface higher densification can cause distortions and cracking.

Concerning MO-57% series, this phenomenon was not observed. One possible reason for this behavior can be related to the fact that the higher the porosity of the material, the lower its conductivity and therefore the greater the depth of penetration of microwaves, promoting a more uniform densification of the segments [11].

Regarding optimum sintering plateau, in the case of MO-77% series, it lies between 722 °C (92%) and 747 °C (93%). In the case of MO-67% series, it is comprised between 722°C (92%) and 772 °C (92%). MO-57 series shows the most wide sintering plateau which extends between 797°C and 872 °C (%ρ > 94%). Thus, it is noticed that the higher is the green density, the lower is the optimum sintering temperature. However, the sintering plateau also decreases, which can result in greater difficulty in controlling the densification of the segments during the MO process, namely due to “shield effect” phenomenon observed in MO-67% and MO-77% series.

Finally, it was observed that, in the case of MO-57% Series, final density values are comprised between 93% – 95%, in the temperature range from 772°C to 847°C. This means that segments have closed residual porosity, which can be eliminated either by

![Graph showing the effect of green density on the densification behavior of MO series.](image)
applying an external pressure or by melting of one of its constituents which may fill isolated pores by capillarity. At 872 °C, there was an increase in density (97%), which suggests that one of the matrix constituents (e.g. tin bronze), has melted thereby increasing the final density. However, the formation of a liquid phase in excess can lead to deformation of the segments.

**Time effect on the densification behavior of segments produced by MO**

Figure 7 shows the effect of dwell time on the densification behavior of MO-57% series. At 822 °C, no significant variation of density values with dwell time was observed. After 3 min of dwell time, segments have already reached a maximum densification around 95%. At 872 °C, there is a slight increase in the final density with increasing time from 97% (5 min) to 99% (30 min). Since the density is higher than 95%, it is likely that the formation of a liquid phase through melting of one of the matrix constituents, may have contributed to the increase in density observed, suggesting that densification was enhanced by a liquid phase mechanism.

On the other hand, at 722 °C, no direct relationship between density and dwell time could be established. Furthermore, it is observed that the standard deviations are higher than 3%, which may be attributed to the fact that such temperature is still an intermediate temperature of the sintering process. Thus, dwell time, at 722 °C, does not have a significant effect on the densification behavior of the resulting segments.

**Optimum MW Thermal Cycle conditions**

As highlighted, the increase in green density results in the decrease of sintering temperature. However, sintering plateau also decreases as green density increases. In addition, it was observed that the highest density values (around 95%) were obtained for MO-57% series. Thus, it is considered that, for the selected matrix, the green density shall not exceed 57%. In view of the fact that for MO-57%, a sintering plateau from 797 °C to 872 °C was observed, an intermediate temperature (i.e. 822 °C) has been selected to sinter both matrix and MMC segments. To ensure better control of sintering temperature during the MW process, it was decided to select a dwell time of 5 min instead of 3 min, used in HP. In summary, optimum MW thermal cycle conditions are shown in Table 1.

**Table 1 - Optimum conditions for MW thermal cycle.**

<table>
<thead>
<tr>
<th>%ρ_{green}</th>
<th>T_{sint} (°C)</th>
<th>t_{dwell} (min)</th>
<th>t_{25°C-822°C} (min)</th>
<th>t_{822°C-350°C} (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>57%</td>
<td>822</td>
<td>5</td>
<td>12</td>
<td>19</td>
</tr>
</tbody>
</table>

**Figure 7 - Effect of dwell time on the densification behavior of MO-57% series**
3.2. Physical and mechanical characterization of MW and HP segments

Density, porosity, dynamic Young modulus, shear modulus and Vickers hardness values for both matrix and MMC segments produced by HP and MW are listed in Table 3. From the density data obtained, it can be estimated that the residual porosity in MW segments is about 5% – 6% (for matrix segments) and 4% – 5% (for MMC segments). As discussed, these values correspond to closed porosity, which is hard to eliminate without using an external pressure.

HP series shows higher values of \( E \) and \( G \) (about 10% – 15%) compared to MW series ones. Among HP series, there was no significant difference in values. Although, in the case of MW segments, MO-MMC series showed slightly higher values of \( E \) and \( G \) (about 6% – 8%) when compared to MO-Matrix series. Since \( E \) and \( G \) are intrinsic properties of a material which depend on chemical composition, microstructure, defects (i.e. pores), among others, the higher porosity observed in MW segments, when compared to HP segments, may explain this difference.

Regarding Vickers hardness, MW matrix segments presented lower values (260 ± 37 HV1) than those determined for HP-Matrix series (331 ± 24 HV1). Considering that the hardness of a material corresponds to the resistance of a material to deformation, indentation, or penetration of its surface, this fact is also related to the presence of higher residual porosity in MW segments.

Table 2 shows that \( \sigma_R \) values determined for the MO-Matrix (1106 ± 120 MPa) and HP-Matrix (1246 ± 78 MPa) series were higher than those obtained for MO-MMC (1039 ± 83 MPa) and HP-MMC (986 ± 120 MPa) series. This difference is related to fracture origin's size (as shown in Table 4).

Table 2 - Flexural strength and Weibull modulus values for MO-Matrix, MO-MMC, HP-Matrix and HP-MMC series.

<table>
<thead>
<tr>
<th>Series</th>
<th>( \sigma_R ) (MPa)</th>
<th>( m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>MO-Matrix</td>
<td>1106±120</td>
<td>11.3</td>
</tr>
<tr>
<td>HP-Matrix</td>
<td>1246±78</td>
<td>16.8</td>
</tr>
<tr>
<td>MO-MMC</td>
<td>1039±83</td>
<td>16.4</td>
</tr>
<tr>
<td>HP-MMC</td>
<td>986±120</td>
<td>9.4</td>
</tr>
</tbody>
</table>

While in the case of MMC segments, fracture’s origin are diamonds located at the surface (or sub-surface) with dimensions of about 400 \( \mu \)m, in the case of matrix segments, fracture’s origin had smaller dimensions, typically in the range of 100 \( \mu \)m – 200 \( \mu \)m.

Regarding MMC series, the measured values for \( \sigma_R \) were similar since the fracture’s origin was the same (i.e. diamonds). Concerning to matrix segments, it was observed by SEM-EDS analysis that fracture’s origin are mostly likely tin bronze agglomerates (as shown in Figure 8). Thus, the slight difference between \( \sigma_R \) values may be related to the fact that HP matrix is more homogeneous owing to the applied external pressure. Indeed, origin’s size is slightly higher in the case of MO-Matrix series, as shown in Table 4.

Table 3 - Density, porosity, dynamic Young modulus, shear modulus and Vickers hardness values for matrix and MMC segments produced either by MW (MO-Matrix; MO-MMC) and by HP (HP-Matrix; HP-MMC).

<table>
<thead>
<tr>
<th>Series</th>
<th>( \rho ) (g/cm(^3))</th>
<th>( % \rho )</th>
<th>Porosity</th>
<th>( E ) (GPa)</th>
<th>( G ) (GPa)</th>
<th>HV1</th>
</tr>
</thead>
<tbody>
<tr>
<td>MO-Matrix</td>
<td>7.78 ± 0.07</td>
<td>94.4 ± 0.09%</td>
<td>5 – 6%</td>
<td>165 ± 3</td>
<td>64 ± 3</td>
<td>260 ± 37</td>
</tr>
<tr>
<td>HP-Matrix</td>
<td>8.24 ± 0.01</td>
<td>100%</td>
<td>-</td>
<td>193 ± 2</td>
<td>76 ± 1</td>
<td>331 ± 24</td>
</tr>
<tr>
<td>MO-MMC</td>
<td>7.80 ± 0.07</td>
<td>96.2 ± 0.09%</td>
<td>4 – 5%</td>
<td>178 ± 5</td>
<td>68 ± 3</td>
<td>-</td>
</tr>
<tr>
<td>HP-MMC</td>
<td>8.11 ± 0.01</td>
<td>100%</td>
<td>-</td>
<td>196 ± 3</td>
<td>75 ± 1</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 4 – Data on origin’s location and size and fracture toughness values for MW and HP series.

<table>
<thead>
<tr>
<th>Series</th>
<th>Origin</th>
<th>Location</th>
<th>$2c$ ($\mu$m)</th>
<th>$a$ ($\mu$m)</th>
<th>$2a$ ($\mu$m)</th>
<th>$k_{IC}$ (MPa.m$^{1/2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MO-Matrix</td>
<td>Tin bronze agglomerates</td>
<td>Surface</td>
<td>209,4±38,3</td>
<td>135,5±34,5</td>
<td>-</td>
<td>14,0±1,5</td>
</tr>
<tr>
<td>HP-Matrix</td>
<td>Tin bronze agglomerates</td>
<td>Surface</td>
<td>202,1±50,0</td>
<td>106,2±18,1</td>
<td>-</td>
<td>14,4±1,9</td>
</tr>
<tr>
<td>MO-MMC</td>
<td>Diamonds</td>
<td>Surface/Sub-surface</td>
<td>406,8±38,3</td>
<td>-</td>
<td>390,7±57,3</td>
<td>14,8±1,7</td>
</tr>
<tr>
<td>HP-MMC</td>
<td>Diamonds</td>
<td>Surface/Sub-surface</td>
<td>499,4±140,3</td>
<td>-</td>
<td>424,6±45,6</td>
<td>15,8±1,5</td>
</tr>
</tbody>
</table>

Figure 8 - SEM-EDX analysis for MO-Matrix series.

As shown in Table 2, the estimated values for Weibull modulus are comprised between 9 (HP-MMC series) and 17 (HP-Matrix series). Thus, it was not observed a clear tendency, regardless of the sintering technique.

According data in Table 4, the difference between the estimated values for $K_{IC}$ was also not significant, suggesting that the materials obtained are quite homogenous.

4. Conclusions

- Microwave heating enhanced the densification process, thereby reducing the optimum sintering temperature between 90°C and 170°C (depending on the green density of the compacts), as compared to FS.

- Regarding MW technique, an increase in green density from 57% to 77% resulted in a decrease of the optimum sintering temperature in 80 °C. Nevertheless, there was also a reduction in the sintering plateau from 75°C to 25°C. Moreover, the highest density value (about 95%) was obtained for the green density of 57%.

- In the present study, the optimum MW conditions were: green density of 57%, sintering temperature of 822°C and dwell time of 5 min.

- MW matrix segments showed lower values for $E$ (about 15%) and $HV1$ (about 20%), than those obtained for FS matrix segments. In the case of MMC segments, the difference between $E$ values was around 10%. These results can be explained by the fact that the pressure used in HP contributes to the elimination of residual porosity.

- Regarding flexural strength, MO-Matrix segments (1106 ± 120 MPa) showed slightly lower values than those obtained for HP-Matrix segments (1246 ± 78 MPa). However, the introduction of diamonds in the matrix increased fracture origin’s size, which resulted in a decrease of $\sigma_R$ values. Therefore, the difference between MMC segments produced by MW (1039 ± 83 MPa) and HP (986 ± 120 MPa) was not significant, which proves that fracture’s origin was the same for both materials.
- Weibull modulus values were comprised between 9 (for HP-MMC segments) and 17 (HP-Matrix segments).
- Concerning to fracture toughness, the estimated values were similar, either for matrix segments (about 14 MPa.m\(^{1/2}\)), or for MMC segments (15 – 16 MPa.m\(^{1/2}\)).
- Thus, MMC segments produced by MW under optimized conditions showed similar mechanical properties to those obtained by HP.

References


