IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

Structural aspects and chemical analyses on cutting process of metallic-ceramic materials

To cite this article: M Lutcanu *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1037** 012033

Structural aspects and chemical analyses on cutting process of metallic-ceramic materials

M Lutcanu[1], B Istrate[1], M Coteata[1], D L Chicet[1], I Ionita[1], C Paraschiv[2], I Stirbu[1], G Badarau[1] and N Cimpoesu[1*]

[1]"Gheorghe Asachi" Technical University of Iassy - Romania, Faculty of Mechanical Engineering, Blvd. Mangeron, No. 59A, Iasi, 700050, Romania
[2]"Grigore T. Popa" University of Medicine and Pharmacy of Iassy, 16 Univ. Street, Iasi, 700115, Romania

[*]Corresponding author's e-mail: nicanor.cimpoesu@tuiasi.ro

Abstract. Preliminary results on the behaviour of metallo-ceramic system during the cutting process were presented. The ceramic layer was obtained, after sandblasting of the substrate, through air plasma spraying with thicknesses of 30 µm on a steel substrate. Layers are chemically homogeneous, without cracks, pores or crevices. The thin layer (30 µm) present discontinuities with uncovered surfaces were the substrate is near in contact with the environment. Cutting process was realized on marking fiber laser equipment (Boron), of 30 watts' maximum power and wave length of 1064 nm. There were obtained two different grooves on the test pieces with the following parameters: laser double pass at speed of 500 mm/sec, pulsed laser of 20KHz frequency and the beam power was set at 50% (around 15W) for the first groove) and at 80% (around 24W for the second groove). Structural, morphological and chemical evaluation of the cutting kerf was realized using scanning electron microscopy (SEM, Vega Tescan LMHII, SE detector, 30 kV, 15.5 mm WD) and energy dispersive spectroscopy (EDS, Bruker X-flash) using automatic/element list mode, Point, Mapping and Line features. This analysis highlighted the type of defects along the cut, respectively the phenomena occurring at the ceramic - metal interface.

1. Introduction

Ceramics are materials with a high number of engineering applications in many industry fields [1,2]. Main characteristics are based on their great properties at upper temperatures, good corrosion resistance, oxidation stability and superior hardness [3-5]. In the same time the brittleness properties present few difficulties final dimensions for industrial applications (respecting dimensional values). The main industrial ceramics are: oxides (alumina-Al_2O_3, magnesia-MgO, Berylia – BeO, Aluminium titanate – Al_2O_3-TiO_2 and zirconia – ZrO_2); carbides (boron carbide – B_4C, tungsten carbide – WC, silicon carbide – SiC, titanium carbide – TiC); nitrides (silicon nitride Si_3N_4, aluminium nitride – AlN, titanium nitride TiN and Zirconium nitride ZrN); borides (titanium diboride Ti_2B and zirconium diboride ZrB_2); silicates (Sialon – Si-Al-O-N, magnesium silicate – $MgOSiO_2$ and mullite – $3Al_2O_3.2SiO_2$) and glass ceramics (soda lime glass – $70SiO_2.10CaO.15Na_2O$ and borosilicate glass – $80SiO_2.15B_2O_3.5Na_2O$) [3,6-9]. Cutting of ceramic materials is not a new procedure being necessary in different domains for many practical applications. These procedures are: conventional methods (abrasive wheel cutting, diamond

saw cutting, mechanical mounting and wire saw cutting); non-conventional methods (wire electrical discharge machining WEDM, laser beam machining LBM, abrasive water jet machining AWJM) and hybrid machining (hybrid laser water jet machining, electrochemical discharge assisted wire machining) [10-12].

In this article we perform a laser cut line on a medium thick ceramic layer (alumina) deposited on a steel substrate and analyze (structural and chemical) the effects of the pulses impact on the material.

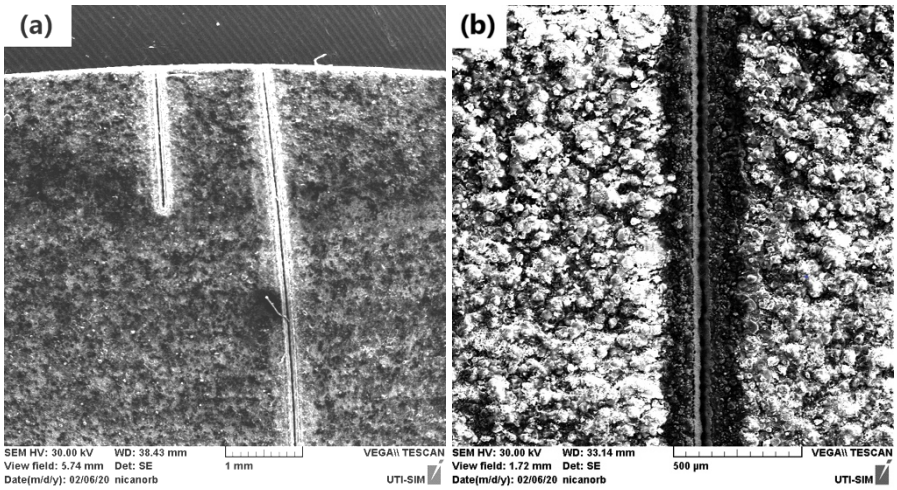
2. Experimental details

Ceramic layers with 30 µm thickness were realized through plasma spraying method using an isolated room with robotized equipment type SPRAYWIZARD 9MCE. The ceramic layer was deposited on a Fe-C alloy as substrate (steel P265G for petroleum transportation pipe). Thin layer was obtained from powders of alumina (Al_2O_3/Metco-105SFP) used for chemical resistance enhancement [8]. Metallic surface of the substrate was prepared before deposition process applying a sandblast operation (Rosler equipment/dry powder sandblasting/Al_2O_3 Fepa 40 (430 µm) at 3 bar pressure [9]). The cutting line and metallic and ceramic surroundings were investigated using scanning electron microscope (VegaTescan LMH II/SE-detector, 30kV/VegaTC software for 2D and 3D characterization). Chemical composition insights were taken using energy dispersive spectroscopy (EDS detector –Bruker, PB-ZAF analyze mode with Automatic/Element list, Point, Line and Mapping features). Ceramic materials present a low machinability [13-15] therefore for mechanical processing high energy processes can be used like laser cutting or EDM - electrical discharge machining [16, 17].

The aim of the laser cutting tests was to analyse the impact area between the laser pulses and the ceramic/metallic material. For cutting process was used a 30 watts max. power/1064 nm wave length marking fiber laser equipment Boron type. The cutting parameters were as follow: laser double pass at speed of 500 mm/sec, pulsed laser of 20KHz frequency and the beam power was set at 50% (around 15W) [18, 19].

3. Experimental results

Experimental sample was structurally and chemically analysed. Insights of the cutting line made with pulsation laser were taken from the ceramic layer and also from the metallic substrate. In figure 1 are presented SEM micrographs as (a) general view, (b) cutting line through ceramic + metallic system, (c) cutting line over two areas with ceramic, on the top part and without ceramic layer (d) details of the cutting line and (e) 3D image of the cutting line. From the structural images, figure 1 (a) - (e) we observe three areas near the cut affected by this process.



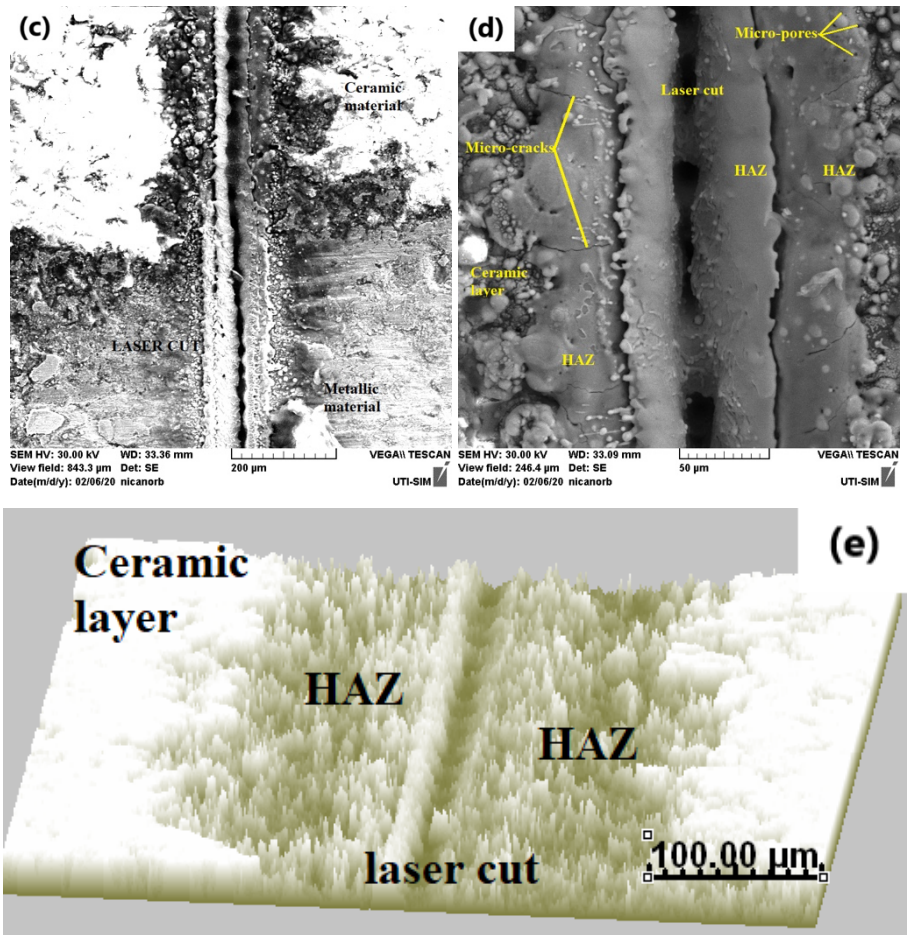


Figure 1. SEM micrographs: (a) general view, (b) cutting line through ceramic + metallic system, (c) cutting line over two areas with ceramic, on the top part and without ceramic layer, (d) details of the cutting line and (e) 3D image of the cutting line.

The linear cut is made by joining points; figure 1 (d), made with pulsation laser at a proper cutting speed. By macroscopic point of view, the cut can be considered straight and without interruptions [20, 21]. Both figure 3 (d) and (e) confirm the nature of the cut as being based on many holes connected by the laser pulse energy impact with the basic material. During the pulsation laser process an exfoliation of the ceramic layer can be observed on the entire heat affected area (HAZ) with widths around 50 µm [22]. At microscopic level few metallic material interruptions can be observed between the laser spots, figure 1 d), fact that confirm the necessity of a lower forward rate. The aspects of the cut line are similar with and without the ceramic layer, figure 1 (c) in the complex material case we observed the removal of the ceramic layer.

The area near the cut observed in figure 1 (d) and (e) present many fissures and longitudinal cracks with pores and micro-pores appeared based on the local heated area from the laser pulse (heat affected zone HAZ). The heat transfer from the laser pulse to the metallic-ceramic material is the main reason why the ceramic layer is removed from the substrate. At macro-scale the removal of the ceramic material seems uniformly done but at microscopic scale, figures (c) and (e) we observed a fluctuation of the ceramic layer based on the center of the laser pulse. HAZ appear on both sides of the cut in equal parts

and as two waves of metallic material (one of 25 μm width near the cut and second larger of 50 μm) [23]. Chemical composition analyze results are presented in figures 2-4.

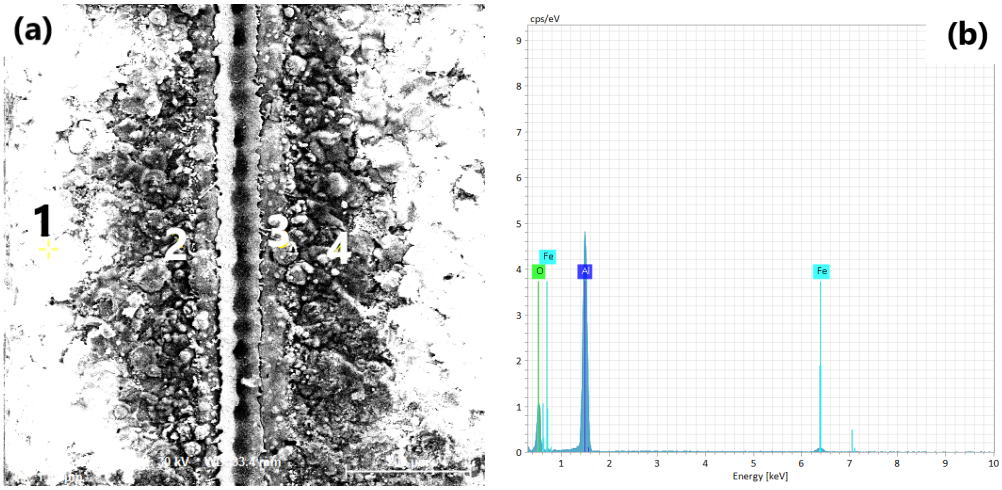


Figure 2. Chemical composition analyze in (a) areas proposed for analyze (points 1-4) and energy spectrum in (b) of identified elements O, Al and Fe.

Qualitative identification of the elements was done through EDS technique and the main elements were identified in energy spectrum from figure 2 (b). Quantitative results of chemical compositions realized in points 1-4 from figure 2 (a) are given in table 1 as weight and atomic percentages (also EDS detector error are given for each element). We follow the evolution of the main elements Al and O characteristic for the ceramic layer deposited on the steel substrate and Fe for substrate (carbon element was ignored because of the small percentage). In point 1 from figure 2 (a) we observe that the ceramic layer is structurally and chemically intact and only a small percentage of iron is observed from the substrate based on the porosity of the layer or the variation of the layer thickness. In the point number 2, figure 2 (a), near the HAZ we observe a decrease of the thin layer elemental components (Al and O) and an increase of iron content [24]. In point 3 a mixture of ceramic layer and substrate exist, based on chemical composition results from table 1, representing a crossing area between the delaminated material near the cut and the ceramic layer with a full integrity.

Table 1. Chemical composition of the experimental sample along the laser cut (points 1-4 from figure 2 (a))

	Al		**O**		**Fe**	
	wt%	at%	wt%	at%	wt%	at%
Point 1	45.03	34.03	50.46	64.32	4.51	1.65
Point 2	28.31	29.87	26.47	47.08	45.22	23.05
Point 3	33.24	28.09	43.92	62.58	22.85	9.32
Point 4	44.58	40.59	31.98	49.10	23.44	10.31
EDS error	1.01		1.8		0.6	

Chemical composition from point 4 present a reduced affected ceramic layer by the laser cut with partial removal of the ceramic layer and the presence of the iron in a bigger amount since in the left part of the cut but, as can be seen from figure 2 (a), in an affected by cut area. Figure 3 present a Line distribution of Al, O and Fe elements for (a) the selected line and (b) component elements distributions.

The Line distribution, figure 3 (a), include all interesting areas from the ceramic layer to HAZ and laser cut. Iron chemical element present a high signal on the both sides of the laser cut were no aluminum signal can be observed. The HAZ area present iron signal and also a percentage of oxygen, smaller comparative with the ceramic layer but existing and confirming an oxidized HAZ area. The inhomogeneity of the ceramic layer is confirmed by the presence of the iron signal in an area where we supposed to have only the ceramic layer, but the decreased signal comparative with the clean substrate, shows only a variation of the ceramic layer thickness and not an entire lack of the non-metallic layer [25].

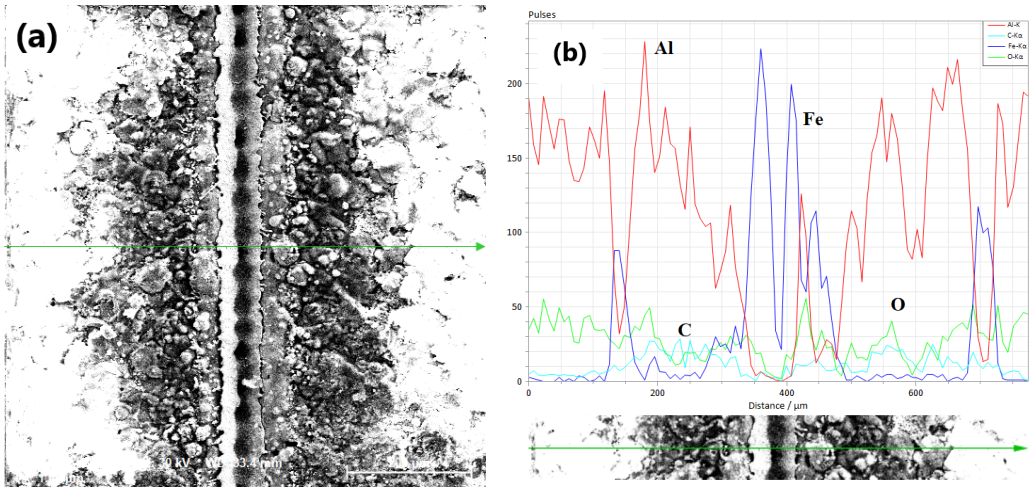
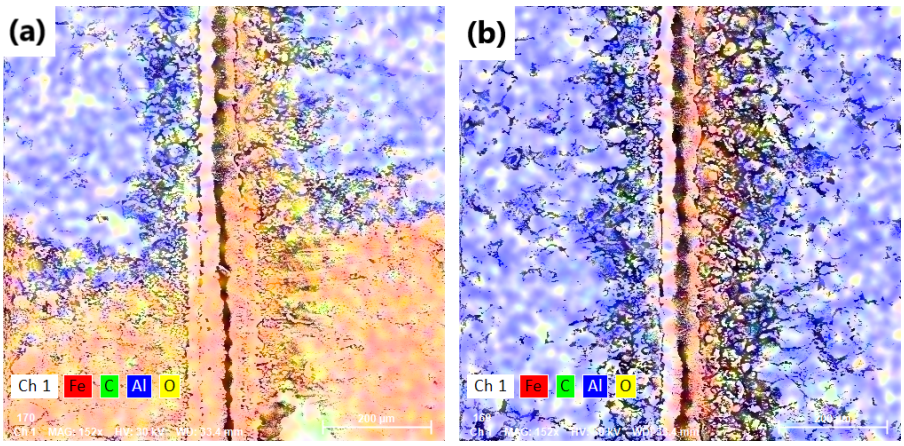


Figure 3. Line distribution of Al, O and Fe elements (a) selected line and (b) elements distributions.

In figure 4 using Mapping distributions of Al, O and Fe, C for different areas of the cut line we can observe, through chemical analyze, the areas affected by the laser cut on different positions during the cutting line. In figure 4 (a) is presented the distribution of elements on two distinct areas, one metallo-ceramic in the top part and the other only metallic both crossed by the cutting line. The laser cut line has a similar aspect in both areas. From figure 3 (b) can be observed that the ceramic layer is more affected on the right side of the cut fact that confirm the chemical analyze from points 1 and 4, table 1, explaining the difference between the iron percentages (4.51 against 23.44 wt%). Along the cutting line we can also observed an oxidized area especially on the right side.



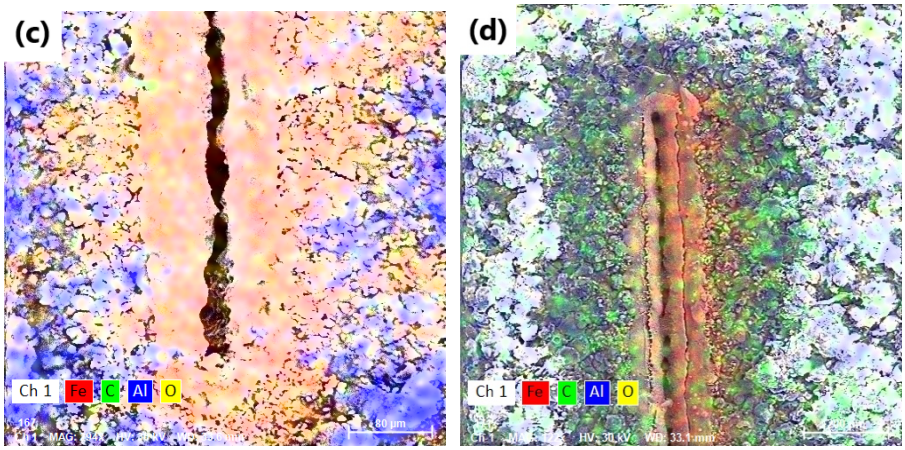


Figure 4. Mapping distributions of Al, O and Fe, C for different areas of the cut line.

In figure 4 (c) and (d) are presented end-points of the laser cut with the elements Fe, C for substrate and Al, O for the covering ceramic layer. On the left side of the cut, near the line we observed stains of the ceramic layer that roughly correspond to the margins of the laser pulse impact areas. By macroscopic point of view, we can consider the cutting line straight but under 100 µm the details, figure 4 (c), present a various line based on the stain let by the impact of the laser pulse with the ceramic/metallic material. The HAZ is big in this case with variations between 50 and 150 µm based on the fastening system of the experimental sample or technological details of the laser cutting equipment.

4. Conclusions

In specialty literature are present different methods for cutting of ceramic materials (conventional, non-conventional and hybrid). In this article few preliminary results (structural and chemical) about the cutting of a ceramic layer deposited on top of a steel substrate are presented and analysed. Aim of the article was to follow these procedure aspects: dimensional neatness, sharpness, substrate quality, surface roughness and heat affected zone (HAZ). By this method obvious flaws are present from the begging of the cutting process on the surface. A totally elimination of the micro-cracks must be considered for further studies. Fissures and micro-cracks appearance is based on the differences between the thermal or mechanical stresses induced during the cutting process and material strength. A proper solution to eliminate fissures from brittle materials is to apply a selection of operational ranges of parameters for the technological process.

As an alternative a proper solution can be hybrid machining in order to gain efficiency in cutting ceramics (specially to improve the surface characteristics near cut like roughness, cracks, pores, exfoliations, HAZ etc.

5. References

[1] Munz D and Fett T 2013 Ceramics: mechanical properties, failure behaviour, materials selection *Springer Science & Business Media*
[2] Liang Y and Dutta S P 2001 *Technovation* **21** 61–5
[3] Tuersley I P, Jawaid A and Pashby I R 1994 *J. Mater. Process. Technol.* **42** 377–90
[4] Rakshit R and Das A 2019 *Precision Engineering* **59** 90–109
[5] Bejinariu C, Munteanu C, Florea C D, Istrate B, Cimpoesu N, Alexandru A and Sandu A V 2018 *Rev. de Chim*. **69** 3586-3589

[6] Samant A N and Dahotre N B 2009 *J. Eur. Ceram. Soc.* **29** 969–93
[7] Mizuno M, Iyama T and Zhang B 2016 Analysis of the sawing process with abrasive circular saw *J. Manuf. Sci. Eng.* **130(1)** 1–15
[8] Florea C, Bejinariu C, Munteanu C and Cimpoesu N 2017 *Advanced Materials Engineering and Technology V Book Series: AIP Conference Proceeding* **1835 UNSP 020053** 10.1063-1.4983793
[9] Florea C D, Munteanu C, Cimpoesu N, Sandu I G, Baciu C and Bejinariu C 2017 *Rev. de Chim.* **68** 11
[10] Enescu F, Irimiciuc S A, Cimpoesu N, Bedelean H, Bulai G, Gurlui S and Agop M 2019 *Symmetry* **11(11) 1391** 2-14
[11] Quintero F, Pou J, Lusquin F, Boutinguiza M, Soto R and Perez-Amor M 2004 *Optic Laser Eng.* **42** 327–40
[12] Mahu G, Munteanu C, Istrate B, Benchea M and Lupescu S 2018 *IOP Mat. Science and Eng.* **444** 032010
[13] Radtke J, Abeln T, Weikert M and Dausinger F 2000 **4088** 252–5
[14] Wang X C, Zheng H Y, Chu P L, Tan J L, Teh K M, Liu T, Ang B C Y and Tay G H 2010 *Optic Laser Eng*. **48** 657–63
[15] Makarov Y, Medvedev O, Khait O, Kurin S, Usikov A, Papchenko B and Helava H *Journal of Physics* **643** 012129
[16] Vijay Praveen D, Ranga Raju D and Jagannadha Raju M V 2019 *Materials Today: Proceedings*
[17] Tuersley I P, Jawaid A and Pashby I R 1994 *J. Mater. Process. Technol.* **42** 377–90
[18] Samant A N and Dahotre N B 2009 *J. Eur. Ceram. Soc.* **29** 969–93
[19] Yamasaka M, Fujisawa M, Oku T and Masuda M 1990 *CIRP Ann – Manuf. Technol.* **39(1)** 333–6
[20] Yan Y, Li L, See T L, Ji L and Jiang Y 2013 *J. of the Europ. Ceramic Soc.* **33(10)** 1893–1905
[21] Cîrlan Paleu C, Istrate B, Paleu V and Munteanu C 2020 **724(1)** 012063-157023
[22] Paleu V, Cîrlan Paleu C, Istrate B, Bhaumik S and Munteanu C 2020 *IOP Conference Series: Materials Science and Engineering* **724(1)** 012064
[23] Panturu M, Chicet D, Lupescu S, Istrate B and Munteanu C 2018 *Acta Tech. Napoc. Series-Appl. Math. Mech. and Eng.* **61(1)** 37-142
[24] Cirlan Paleu C, Paleu V, Istrate B, Cimpoesu N and Munteanu C 2019 *IOP Conference Series: Materials Science and Engineering* **591(1)** 012007
[25] Chen X, Ji L, Bao Y and Jiang Y 2012 *J. Eur. Ceram. Soc.* **32** 2203–11