Study of the Dielectric Dispersion Phenomena for Al_2O_3/Al Cermet Composite at Room Temperature

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Abstract
A cermet composite Al_2O_3/Al had been prepared in different concentrations of Aluminum metal (0, 10, 20, 30, 40, 50) Wt%, the samples have been formed at pressures (50, 100, 150) bar into pellets with diameter (15) mm and thickness (4) mm by cold pressing, the sintering temperature 800 °C for 2 hrs. in vacuum, physical, microstructure, dielectric properties were studied, physical tests showed that as the concentration of Al increased, the practical density decreased and the porosity decreased also specially at the region of concentration from 40% to 50% of Al, the microstructure shows the liquid phase is happening, dielectric measurement shows that the dielectric constant, loss factor and loss tangent were decreased as increasing frequency.
Keywords: Cermet, Alumina, Compaction Behavior, Dielectric dispersion.

1. INTRODUCTION

Composite materials are multiphase materials obtained through the artificial combination of different materials without any chemical reaction in order to attain properties that the individual components by themselves cannot attain (Najem, 2011).

The term cermet is used to describe a ceramic matrix material having metallic particles dispersed in the ceramic body. The term is also used to describe the reverse, that is, a metal matrix having dispersed therein refractory or ceramic materials which impart ceramic-like characteristics to the cermet, combination of the desirable qualities of ceramics with those of metals has led to materials called cermets, from combining and contracting the words ceramic and metal, Oxide ceramics are strong and resistant to both creep and oxidation at high temperatures. However, for many applications, they are brittle and susceptible to thermal shock failure. On the other hand, metals, which are ductile and less prone to thermal shock failure are susceptible to destructive oxidation at high temperatures (Sowman and Kaar, 1987).

Alumina (Al_2O_3) possesses favorable physical and chemical properties such as high strength, hardness, elastic modulus and excellent resistance to thermal and chemical environments, However; its applications are somewhat limited because of poor toughness and inferior thermal resistance. On the other hand, most structural ceramics present poor electrical conductivity. It has been reported that the incorporation of some amounts of small-size metal particles into an Al_2O_3 matrix, can significantly improve both the toughness and electrical properties.(Miranda-hernández et al. 2006), while Light metals like aluminum, titanium, magnesium are gaining use as structural materials in engineering components. Their low density combined with reasonable tensile strength and ductility has led to their extensive use in the field of aviation and automotive industries, however; they have low wear, erosion and abrasion resistance which limit their use For, many of the engineering applications (Tailor et al. 2013).

2. Literature Review

Jose G.miranda et al. (2009) had produced Al_2O_3 matrix cermets from mechanically mixed powders containing different metals (Al, Fe or Ti) as reinforcement, the powder mixture was compacted to cylindrical samples, which were subjected to pressure –less sintering 1500 °c for 1 h., it was found that microstructure of cermets with Al and Fe, consisted of equally distributed metallic particles in the Al_2O_3 matrix, also that incorporation of a ductile metal in to a hard ceramic matrix improves its fracture toughness (Miranda-Hernández et al. 2009).

Properties of permeable cermets were studied in 2011 by several researchers. In this study, cermets were prepared from three different types of aluminum powder, the effect of the synthesis parameters were discussed on structural-mechanical and catalytic properties of cermets in isobutane dehydrogenation, it was concluded that hydrothermal treatment of blends with aluminum metal powders provides an efficient technique for preparation of mechanically strong monolith composite materials with developed nanopore structure along with a relatively high fraction of macropores (Tikhov et al. 2011).

In 2012 Copper was strengthened with 20 and 30 vol. % of alumina particles characterized by diameter of (3-6) µm. The copper based composite materials were manufactured by the squeeze casting method, the microstructure and physical properties: Brinell hardness (HBW) and density were characterized, metallografic examinations showed that alumina particles were uniformly distributed in the copper matrix. Wear investigations were performed applying the tribological pin-on-disc tester, it was concluded that when composite material cu-ETP matrix strengthened with alumina particles can be manufactured by squeeze casting method and are characterized by large hardness (three times larger than pure copper), also that materials containing ceramic particles are characterized by three times better wear resistance comparing to unreinforced copper matrix (Kaczmar et al. 2012).

S.L. Swartz et al. (1992) had investigated the dielectric properties of unreinforced lanxide TM Al_2O_3/Al composites over a wide range of temperatures and frequencies; it was found that, as the metal contents was decreased, the composites changed from conducting to insulating along the growth direction. When the metallic phase was removed completely, the porous alumina ceramic maintained anisotropic dielectric properties. A dielectric relaxation phenomena was observed in some samples of both as grown and thermally treated material, and was attributed to an unidentified impurity effect (Swartz et al. 1992).

3. Aim of the work

This paper aims to prepare a cermet composite (Al_2O_3/Al) in different concentrations of Al, to study the compaction behaviors through the physical and microstructure measurements, all that to study the dielectric dispersion phenomena by studying the dielectric measurements results.

4. Materials and Methods

The raw materials are powders of Alumina (Al_2O_3) and Aluminuim (Al), concentrations prepared are Al_2O_3-(0,10,20,30,40,50) % Al, the mixing process took 2hrs. by using the magnetic stirrer, the pressing process was by single action pressing at cold, and done by cylinder steel mould , the samples were pressed at (50,100,150) bar for 3 minutes, the sintering process was done for 2hrs. (5°C/min.) at 800 °C in vacuum, the specimens were left in the furnace until they gradually cooled to the room temperature, after that we can take them out of the furnace, all this we have to do in order not to force the specimens to be cracked.

The characterization of the synthesized products is carried out of the following way: Sample's density is evaluated by Archimedes method and the porosity was calculated by the equation (1) (chun usei cheng et al. 1988):

$$P=1-\frac{\rho\ experimental}{\rho\ theoretical}*100\% \tag{1}$$

where ρ experimental is the experimental density measured by archimedes method, ρ theoretical is calculated by the equation (2) (AHMAD, 2007):

$$(\frac{1}{\rho th}=\frac{Xm}{\rho m}+\frac{Xr}{\rho r}) \tag{2}$$

Where: ρth theoretical density for mixture(gm/cm^3).
ρm theoretical density for alumina(3.9 gm/cm^3).
ρr theoretical density for aluminum (2.7 gm/cm^3).
Xm weight percent for alumina powder.
Xr weight percent for aluminum powder.

The microstructure of the composites is observed by the scanning electron microscopy (SEM) in vacuum with zoom capability from 4mm to 5 µm, finally; the dielectric measurements (including resistance and capacity) were measured by LCR meter device at room temperature.

To study the phenomena of a dielectric dispersion there is some basics we have to know: The capacitance C of a capacitor is defined as the ratio of the charge Q on conductors to the potential difference V between the plates of the capacitor as shown in the equation (3) (KADHIM, 2014):

$$C=Q/v \tag{3}$$

When an alternative electric field (v) is applied, its angular frequency (ω) between the capacitor's plates in the case of existing a dielectric substance between the two plates, a part of the electrical energy will transform to dissipated thermal energy which is known as lost energy denoted by dielectric loss (tan δ).

If we have a capacitor with dielectric substance between its plates, that capacitor connected to an Ac voltage source by a resistance connected parallel with the source, so the total current (I) through the capacitor can be resolved into two components: (I_C) the current that flows through the capacitor and (I_R) the current that flows through the resistance, if we consider that capacitor has capacity C_p and resistance R_P connected at parallel as in figure 1, the phase diagram would be as in figure 2.

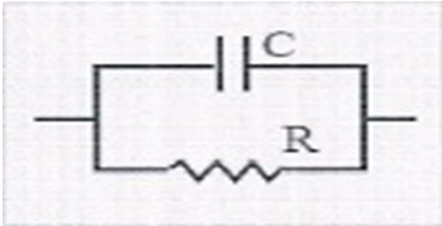

Figure 1. Electric circuit of a capacitor connected to resistance by parallel.

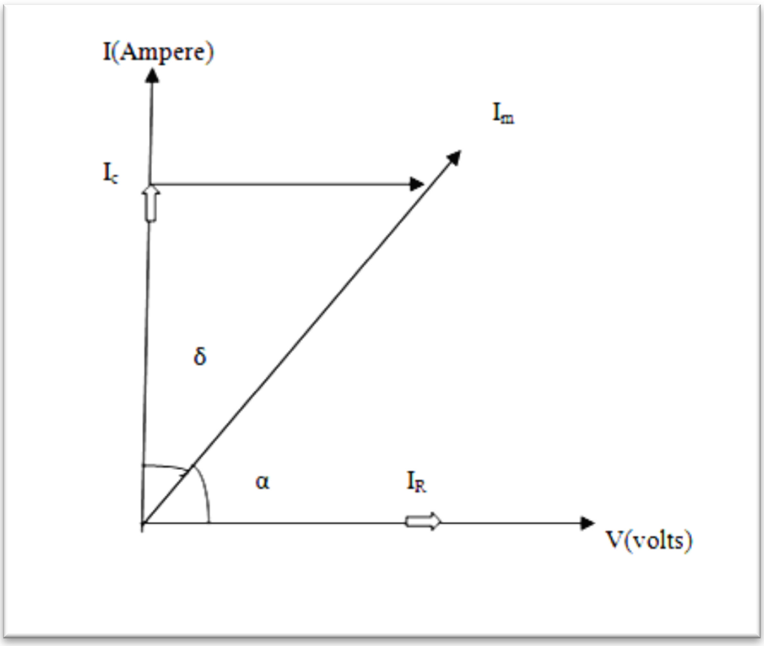

Figure 2. The phase diagram of the circuit in fig.1.

Where: α is (phase angle), δ is (loss angle).
The relation that relates C_p, R_p and ω is:

$$\tan\delta = \frac{1}{\omega\ Cp\ Rp} \tag{4}$$

Where: $\omega = 2\pi f$, f is the frequency in (Hz) .
If tan δ was so small that means the substance is good dielectric substance and the loss energy will be neglected, while; if tan δ was big that means the dissipated energy is also big. (Benlahrach et al. 2006, Saburi, 1959).

5. Results and Discussion

We notice in figure 3 (a, b, c) below in general not in specific, the density of its two kinds (green and practical density) is increasing with the pressure increment, especially at 150 bar in fig. 3 (d), that can be explained when the powder is pressed, the atoms will deform and pressed to each other that became more coherent and the connection area between them will increase with the increase of pressure and that agrees with (HAMZA, 2008) despite the different sintering temperature they used, also, we notice from fig. 3 (a, c) that the green density of the cermet composites is greater than the practical density of them, while fig. 3(b) is the opposite, this decreasing and increasing between the green and sintering density depend on the amount of gases that expanded at the sintering process and increase the porosity percent and decrease the sintering density of the sample, the amount of trapped gases inside the sample determine whether the samples density after sintering decrease or increase, the increase of sintering time and sintering temperature increase the density after sintering after elimination of trapped gases, also we notice that the practical density decrease with the increase of Al content, that can be explained, when the samples are sintered and the sintering temperature accedes the melting point of aluminum which mean we have liquid phase sintering and the atoms of both alumina and aluminum will experience a good compaction because of the melted aluminum particles that make good adhesion with the alumina particles, by flowing the melted aluminum into alumina pores, and because of the density of aluminum is lower than the density of alumina, that will cause a decrease in the composite practical (sintering) density than in the green ones and that agrees with (AHMAD, 2007) despite they didn't accede the aluminum melting point.

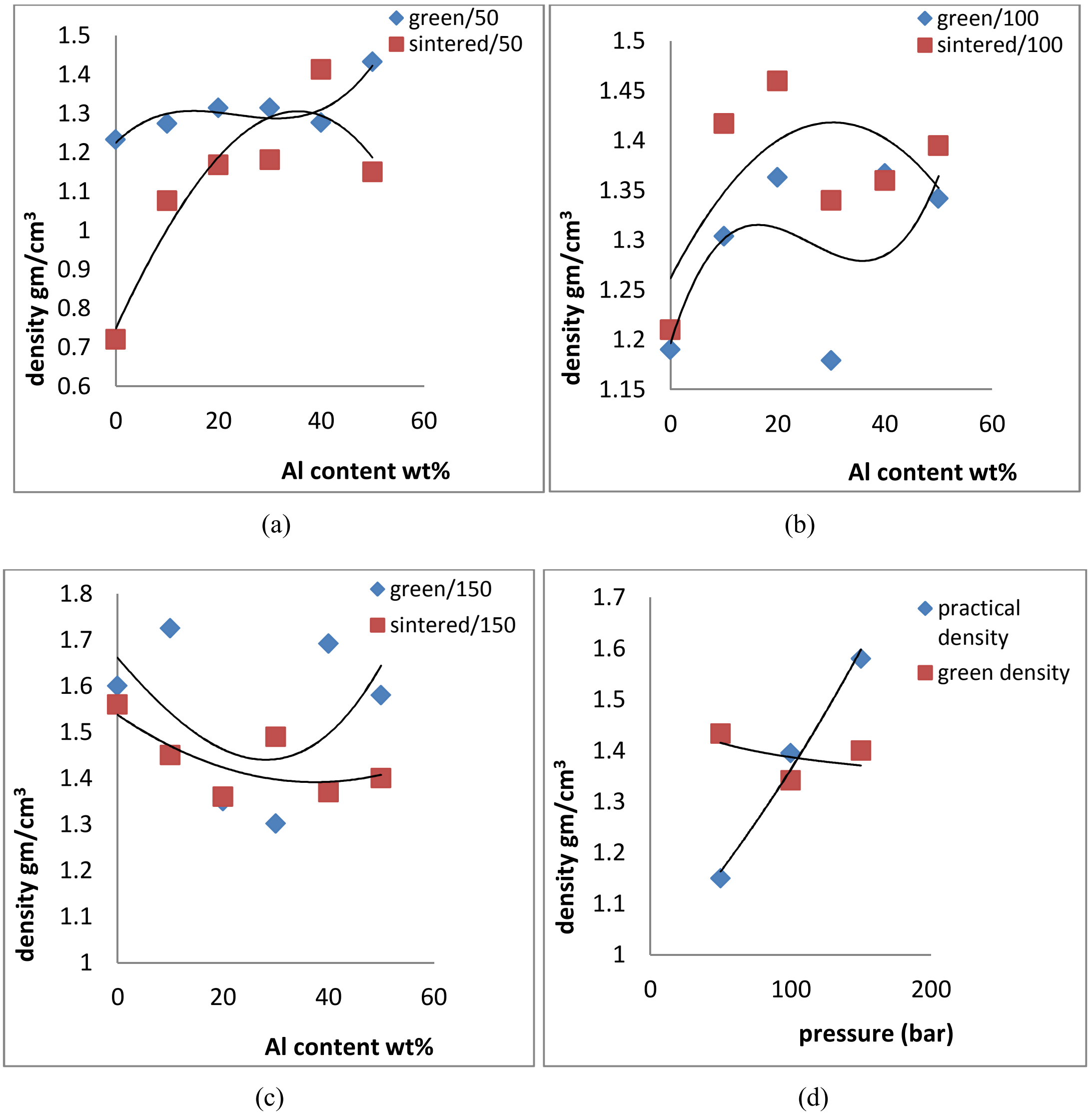

Figure 3. (a, b, c) the effect of Al content on the (green, practical) density of the Al_2O_3/Al composite at (50, 100, 150) bar respectively (d) the effect of the pressure on the (green, practical) Al_2O_3-50% Al composite.

In fig. 4 (a, b, c) we notice that the porosity decrease as the Al content increases also in fig. 4 (d) [we focused in fig. 3 (d) and in fig. 4 (d) on the concentration of 50% Al because the general behavior we have in fig. 3 (a, b, c) and in fig. 4 (a, b, c) in the range of (40 to 50)% of Al has Almost best physical properties and from that base the SEM and dielectric measurement were tested on this concentration (50%Al)] the porosity decrease with increasing pressure, this is a consequence of the fact that, the aluminum is a ductile material and much capable of compacting and consolidating than alumina, so it can fill the porosities that exist mostly because of the alumina, so; as the aluminum content increases the apparent porosity decreases and that agrees with (AHMAD, 2007).

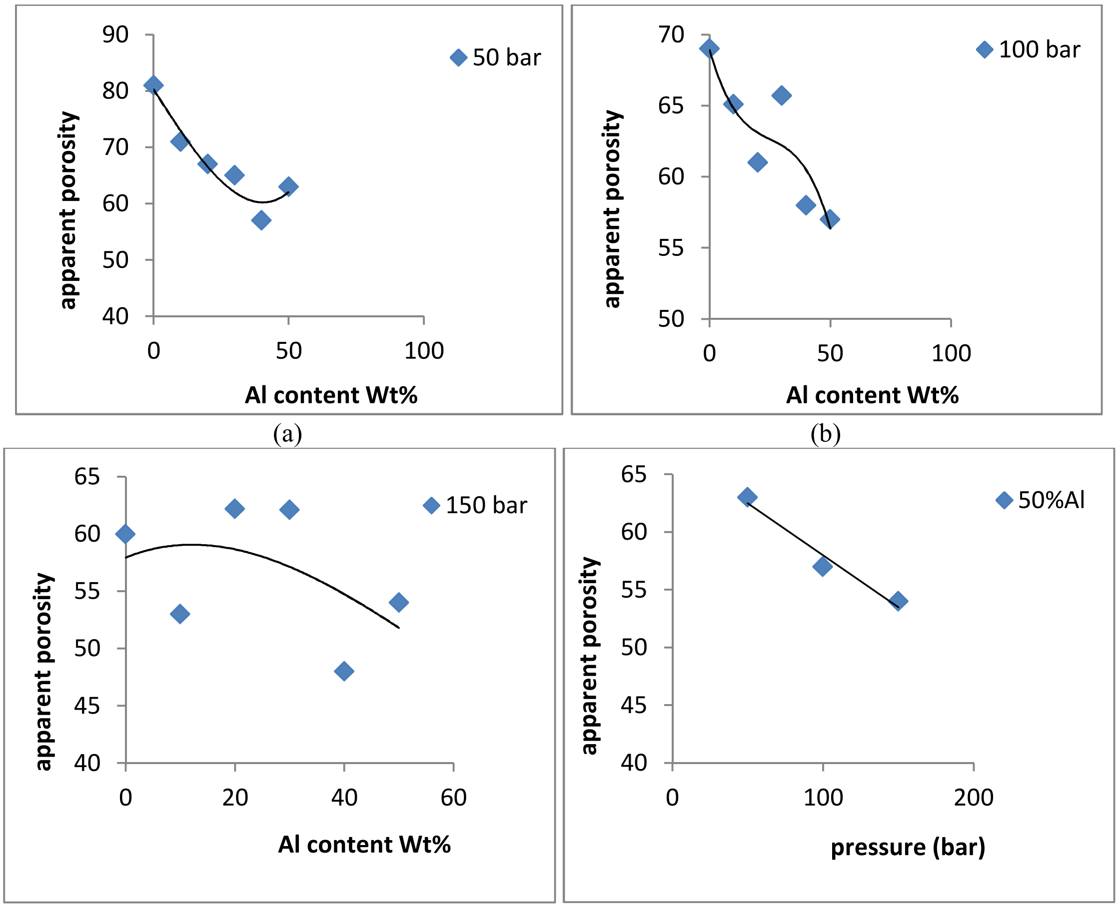

Figure 4. (a, b, c) the effect of Al content on the apparent porosity of the Al_2O_3/Al composite at (50, 100, 150) bar respectively, (d) the effect of the pressure on the apparent porosity of the Al_2O_3-50% Al composite.

Fig. (5) shows the result of the scanning electron microscopy (SEM) for the cermet composite A_2O_3-50%Wt Al pressed at 150 bar, sintered at 800 °C for 2 hours in vacuum, from fig.5 we notice the porosity and the aluminum flowing between the alumina particles as it is obvious from the figure, this is a sequent of the sintering temperature that accede the aluminum melting point (660°C), this can be explained because of the high porosity ratio that make the metal's melt to inter the ceramic porosities because of the capillary force of the metal.

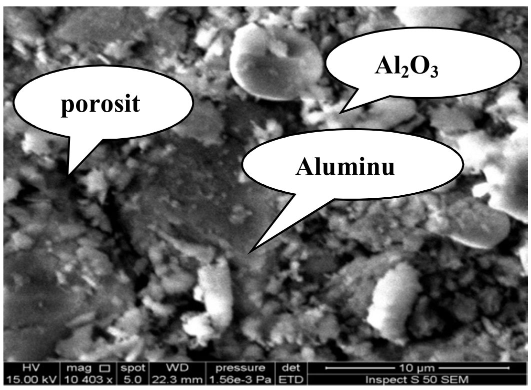

Figure 5. Scanning Electron Microscopy (SEM) micrographs for Al_2O_3-50%Al composite in vacuum at 10 µm.

Figure 6: a-real part (relative permittivity), b-the dielectric loss and, c-tan δ with frequency of range (25049.75-10^6) Hz at room temperature for the cermet composite Al_2O_3-50%Wt Al formed at pressure (150) bar which have been sintered at 800 °C for 2 hours in vacuum, this figure shows that the dielectric properties decline with the increase of frequency, that behavior is called **Dispersion**, this dispersion can be explained as a sequent of the

dipoles and their dependence on the field frequency that have been applied, so that, when an AC voltage source is applied, the direction of the electric torques and of the polarization will be changed with changing of the field polarization, if the changing was little, that results that the polarization will continue with the field alternation without retreat mentioned .If the frequency is increased, the torques wouldn't continue with alternating electric field, so; they will start to vibrate retreating the electric field. If the frequency increased so much, the torques will not be able to continue with the field, this effectiveness leads to the dispersion, this phenomena is called (dielectric dispersion), where the directional polarization will be with the direction of the field at low frequencies, while at the very high frequencies, the direction would be neglected, that's what called dielectric relaxation .Also we notice from fig.6 there was no region that the field appear to be settled in it, maybe there is no lower frequencies than (25049.75) Hz that enable us to reach this settled region. This dispersion happened here has a relation with charges movement (electrons), where the electrons movement and their collision of each other, make them reflected and delay would be happen in their movement and in their march completion, and that cause delay and obstruction in the current, as Haywang explained in 1971 (Heywang, 1971), this dispersion of the resistivity is a sequent of the small grain boundaries with the increase of frequency, so that at high frequencies the semiconductor grains became monolith to each other without any resistance mentioned.

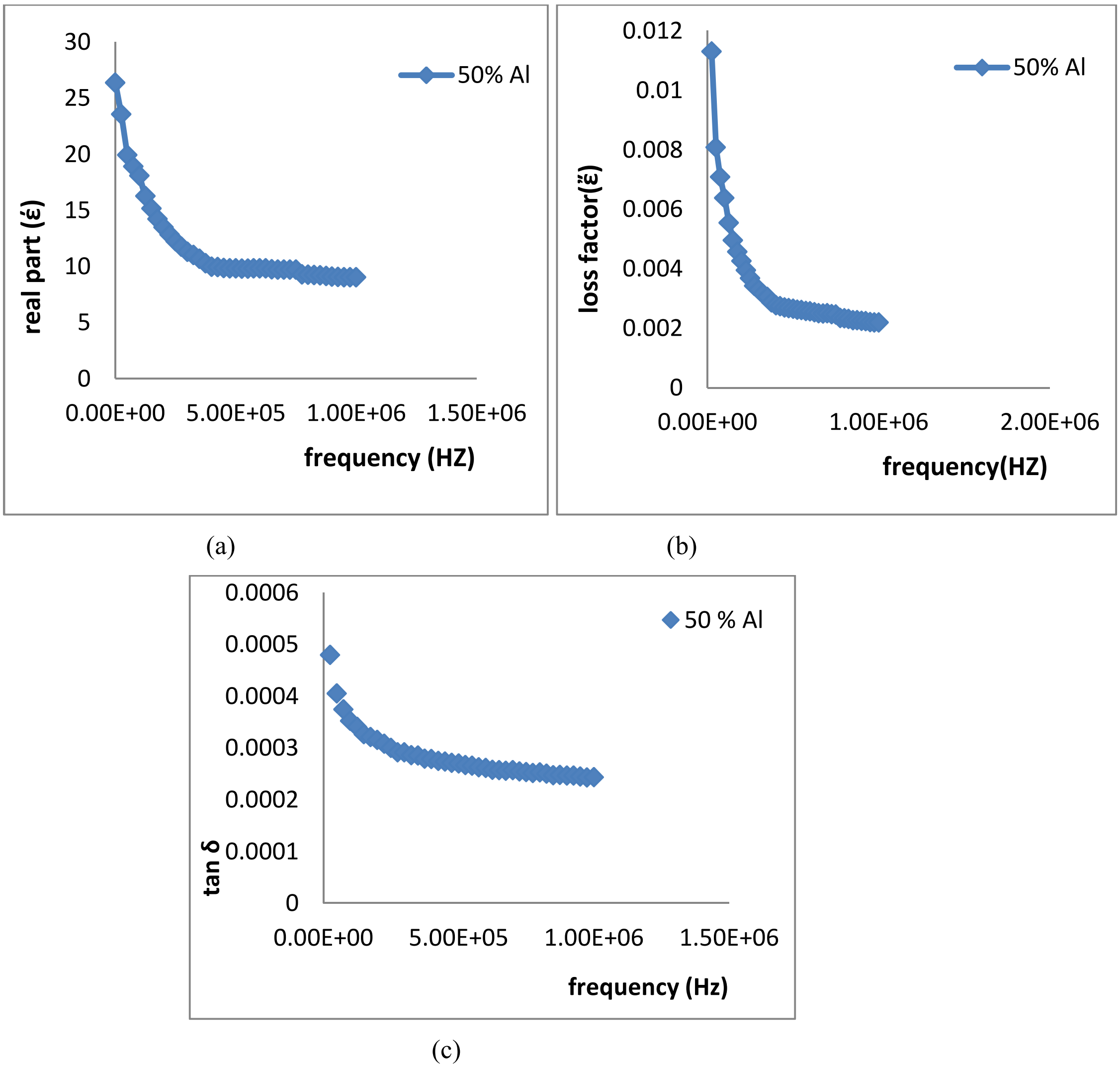

Figure 6. the effect of the frequency on the Al_2O_3-50% Al composite for: a-real part (ɛ́), b-dielectric loss (ɛ̈), c-tan δ.

6. Conclusion

1) The increase in sintering process wouldn't happen unless the chosen temperature make the liquid phase happen.
2) The compaction and shrinkage behaviors and the microstructure for the prepared composite, play an important role in dispersion behavior and in dielectric properties for this composite.

3) Dispersion behavior that has a relation with electrons movement and their collision between each other, influences by the grain boundary region, and decreases at the high electric frequencies, that results to decrease all of dielectric constant, loss tangent and dielectric loss index, because at the high frequencies, the grains (conductors and semiconductors) become so close to each other that the width of the potential barrier became narrower.

References

Najem, S.H. (2011), "Machinability of Al-2024 reinforced with Al_2O_3 and/ or B_4C", 1-13.
Sowman, H.G. and Kaar, D.R., (1987), "GRADED REFRACIORY CERMET ARTICLE" Patent Number: (4,713,300), 4.
Miranda-hernández, J.G., Moreno-guerrero, S., Soto-guzmán, A.B., and Rocha-rangel, E., (2006), "Processing Research Production and characterization of Al_2O_3 -Cu composite materials", 7, 4, 311–314.
Tailor, S., Mohanty, R.M., and Soni, P.R., (2013), "A Review on Plasma Sprayed Al-SiC Composite Coatings", Journal of Materials Science & Surface Engineering, 1, 1, 15–22.
Miranda-Hernández, J.G, Rocha-Rangel, E., and Díaz de la Torre, S., (2009), "Synthesis, microstructural analysis and mechanical properties of alumina-matrix cermets", Epa. - J. Silic. Based Compos. Mater., 62, 1, 2–5.
Tikhov, S.F., Pakhomov, N.A., Nemykina, E.I., and Salanov, A.N., (2011), "Porous Ceramic Matrix Al_2O_3/ Al Composites as Supports and Precursors for Catalysts and Permeable Materials", 196 - 210.
Kaczmar, J.W., Granat, K., Grodzka, E., and Kurzawa, A., (2012), "Tribological properties of Cu based composite materials strengthened with Al_2O_3 particles", 13, 2, 33–36.
Swartz, S.L., White, D.R., and Cross, L.E., (1992), "Dielectric properties of lanxide ^{TM} Al_2O_3/Al composites", *J. Mater. Sci.*, 27, 3932–3938.
Benlahrach, M.T. et al, (2006), material science in semiconductor processing, 115.
saburi, O., (1959), J.phys.soc.Japan, 14, 97-1159.
chun usei cheng, Rose.lnnes, A.c., MCN Allorc, N., Hamer, M.A., and Birchall, J.D., (1988), superconductor, sci.Technol., 1, 113.
AHMAD, H.D., (2007), ''preparation of ceramic matrix composites materias (Al_2O_3/Al) for technical application'', 53, 67,69.
HAMZA, M.T., (2008), ''The effect of time and temperatures of firing in the mechanical properties of Aluminum compact which reinforced by silicon oxide'', 78.
Heywang, w., (1971), J mater .Sci, 6, 21.