



## Physical and Morphological Properties of Hard- Soft Ferrite Functionally Graded Materials

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(Received 20 December 2016; accepted 31 October 2017)

<https://doi.org/10.22153/kej.2018.10.007>

### Abstract

Functionally graded materials (FGMs), with ceramic –ceramic constituents are fabricated using powder technology techniques. In this work three different sets of FGMs samples were designed in to 3 layers, 5 layers and 7 layers. The ceramic constituents were represented by hard ferrite (Barium ferrite) and soft ferrite (lithium ferrite). All samples sintered at constant temperature at 1100°C for 2 hrs. and characterized by FESEM. Some physical properties were measured for fabricated FGMs include apparent density, bulk density, porosity, shrinkage and hardness. The results indicated that the density increase with the increase the number of layer. Lateral shrinkage is one of the important parameter for estimating the quality of component gradation in an FGM structure. The Vickers hardness show higher value at FGM7, Finally the FESEM images showed a gradation in microstructure within the system from plate- like structure for the hard ferrite to spherical structure for the soft ferrite.

**Keywords:** *Functionally graded materials; physical properties of FGM; ceramic; hard ferrite; soft ferrite.*

### 1. Introduction

In the previous couple of years, the usage of ceramic materials has amazingly expanded in various applications in view of the particular properties of these materials in examination with metals and polymers. The gainful qualities of ceramic materials are hardness, inflexibility, grating durability and low thickness. Ceramics are a sort of materials by and large characterized as "inorganic, nonmetallic solids". They have the colossal degree of motivation behind every single known material. The most recent decades have seen the advancement of the tremendous capability of practical earthenware production in light of interesting dielectric, ferroelectric, piezoelectric, pyro-electric, ferromagnetic, magneto-resistive, ionic, electronical, superconducting, electro-optical, and gas-detecting properties. Similar logical extensions additionally have occurred in

auxiliary ceramic. Thermal, chemical, and mechanical steadiness of numerous oxide and nonoxide mixes have put the reason for improved handling, which prompted an upgraded level of microstructure outline and flaw control. This has progressively directed in at no other time seen improvements in mechanical conduct and in the precision of the properties of parts and devices [1]. Ferrites are categorized mainly into three sets with various crystal types. They are spinel, Garnets and Magneto-plumbite. Spinel ferrites have a cubic structure with general equation  $MO Fe_2O_3$ , where M is a divalent metal particle, similar to Mn, Ni, Fe, Co, Mg, and so forth. Garnets have a complex cubic structure having a general equation  $M_3Fe_5O_{12}$ . The third sort, magneto-plumbite, has a hexagonal structure with general recipe  $MO. Fe_{12}O_{18}$ . The most critical in the arrangement of magneto plumbite is barium ferrite  $BaO Fe_{12}O_{18}$ , which is a hard ferrite [2]. The quick advancement of new

high innovation requests an ever increasing number of new materials with various uncommon attributes or capacities. Under some serious boundaries, for example, super high temperature, conventional materials may not serve. Another material idea, practically evaluated materials (FGMs), has been proposed to meet the prerequisite which typically incorporate diverse material constituents, for example, ceramic and metal. FGMs have received significant attention in many engineering applications since they were first outlined in 1980s. They are composite materials, microscopically inhomogeneous, in which the mechanical properties change smoothly and continuously from one surface to the other. Compared with classical laminated composite materials, FGMs supply outstanding thermo-mechanical performances under given loading conditions. FGMs can be utilized to enhance creep behavior, fracture toughness of machine tools, wear resistance, oxidation resistance of high temperature aerospace and automotive components and so on .[3] (Jaworska, et.al.2006) Studied functionally graded cermets. Materials were acquired using free sintering at vacuum and the high temperature-high weight sintering system. Practically evaluated cermets have greater amount of hard stage in the surface layer and lower cooperation of this stage in the body outline. FGMs were set up by the layers pressing operation and the diffusive statement operation. Material with 55 wt.% of TiC and 45 wt.% of (Ni,Mo) was incorporated. The stage's structure of this material was analyzed. (Shabana,et.al.2006) Modeling the development of stress because of differential shrinkage in powder-processed functionally graded metal-ceramic composites during pressureless sintering. This model can be used to decide helpful shrinkage rates and slope structures for a given segment geometry that will restrict the part from breaking amid pressureless sintering by adjusting the advancement of quality, which should be a power law capacity of the porosity, with the improvement of stress. To estimate this model, the powder blend is evaluated as a three-stage material including voids, metal particles, and artistic particles. A micromechanical thermal elastic- viscoplastic constitutive model is then proposed to show the thermomechanical conduct of the composite microstructure.

(Shahrjerdi,et.al.2011), demonstrated the functionally graded metal-ceramic composite synthesized through weight less sintering. The unadulterated metallic and ceramic parts are Titanium (Ti) and Hydroxyapatite (HA), which were situated at the finishes of a round and hollow

example. FG tests are set up with blending extents of 100:0, 75:25, 50:50, 25:75, 0:100. The barrel shaped specimens had a thickness of 6 mm in size and 20 mm span. Tests are manufactured by utilizing carbon cylindrical die. The ideal thermal load mapping is picked up tentatively. The properties of all FGM items are portrayed by shrinkage, optical magnifying instrument, filtering electron magnifying instrument (SEM), vitality dispersive spectrometry (EDX) and hardness test. (Mahamood,et.al.2012), Proposed an overview of synthesizing method , field of application, some new research studies the need to concentrate more research attempt on improving the most promising FGM synthesizing method (solid free form SFF). Improving the performance of SFF processes and extensive studies on material characterization on components produced will go a long way in lower the manufacturing cost of FGM and increase productivity in this respect. (Mustapha, et.al.2013), suggested an extensive review on the various synthesizing methods of FGMs composed by metallic and ceramic phases. Synthesizing methods in this field of work have comprising many concepts from various background of gradation methods and consolidation or sintering methods (Yu, et.al.2013) Suggested micromechanics display represents multi-stage heterogeneity and discretionary number of layers. The impact of geometries and unmistakable flexible material properties of every constituent and voids on the viable versatile properties of FGM is examined. Numerical cases of different practically reviewed materials are introduced. The predicted elastic properties resulted from the present model work in well with experimental results from the literature. (Fadhil, et.al.2017) Studied dielectric and magnetic properties of nanoferrite functionally graded materials with ceramic -ceramic constituents are fabricated using powder technology techniques. In this work three different sets of FGMs sample were designed in to 3 layers, 5 layers and 7 layers. The ceramic constituents were represented by hard ferrite (Barium ferrite) and soft ferrite (lithium ferrite). All samples sintered at constant temperature at 1100°C for 2 hr. The magnetic properties showed an increase in coercive force ( $H_c$ ) with increased number of layers. The dielectric properties measured at room temperature with constant frequency 1 MHz. The results showed the dielectric constant increase with the increase the number of layers from  $(1.39 \times 10^{-2})$  to  $(2.83 \times 10^{-2})$ .

According to the above literature reviewing, it's clear that the fabrication of hard ferrite/lithium ferrite functionally graded materials is a very new

area for investigation that based on using graded ceramic materials.

The aim of this work is Fabrication a functionally graded materials (FGMs) from hard ferrite and soft ferrite materials in three different set of multiples layers and then studying the physical and morphological properties of the system.

## 2. Experimental Procedure

### 2.1. Starting Materials

Nano barium ferrite ( $BaFe_{12}O_{19}$ ), Nano lithium ferrite ( $LiFe_5O_8$ ).

### 2.2. Preparation of Hard/ Soft Functionally Graded Material

The start material used to fabricate FGM sample were Nano barium ferrite and Nano lithium ferrite, are weighted in the proportions as shown in Table (1). The formation of a discrete layered graded structure at first requires mixing of the base materials to appropriate composite powder composition. The FGM structure consists of the two base materials on either end of the specimen,

with the desired compositional gradient layered between the two as shown in Fig. (1). The FGM system are composed of (3, 5, and 7) layers with thickness (4.5, 8, and 12) mm, respectively. The weight of FGM layer will measured by sensitive balance, the constituents powder were arranged according to the volume fraction of layer starting from lithium ferrite to barium ferrite as mentioned in table (1), After that compacting practice were done under 20000 Mpa load pressure. Each sample was subjected to sintering under temperature of 1100°C for 2 hr. The sintering heating cycle including a slow heating rate with 5 °C/ min, (see Fig. 2). All sintering practices were carried out by using electric furnace.

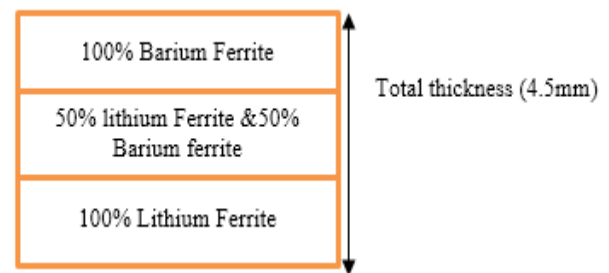


Fig. 1. Sketch represents FGM system with 3 lay

Table1, FGM profil

3 layer	5 layer	7 layer	Weight of LIM(g)	Weight of BaM(g)	Total thickness
100% LiM	100% LiM	100% LiM	0.4	0	4mm
	75% LiM+25% BaM	80% LiM +20%BaM	0.32	0.08	
		65%LiM+35%BaM	0.3	0.1	
		50%LiM+50%BaM	0.26	0.14	7mm
50%LiM+50%BaM	50%LiM+50%BaM	50%LiM+50%BaM	0.2	0.2	
		35%LiM+65%BaM	0.14	0.26	11mm
	25%LiM+75%BaM	25%LiM+75%BaM	0.1	0.3	
100% BaM	100% BaM	100% BaM	0	0.4	

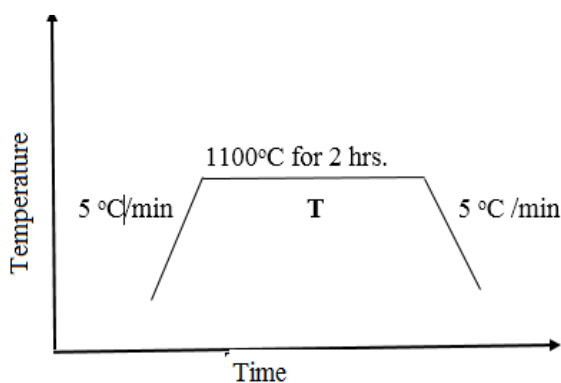


Fig. 2. Single heating cycle of the applied sintering process.

## 3. Results and Discussion

### 3.1 Physical Properties

#### 3.1.1 Density and Porosity

The (bulk and apparent) density for FGM sample are shown in Fig. (3). Porosity for FGM system was also shown in Fig. (4). the variation of density between the different FGM sample with (3, 5, 7) layer which shown slightly an increase of density with the increase the number of layer; the reason behind such improvement is related to high densification, high homogeneity and good blending between the layer of FGMs [7]. The

results of density of prepared FGM sample accompanied by almost slightly increase of porosity at constant sintering temperature.

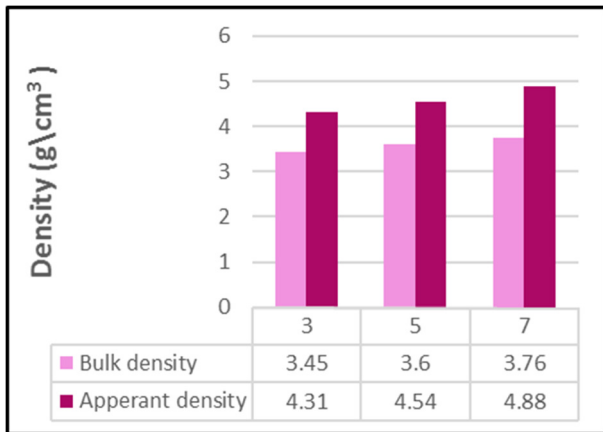


Fig. 3. Density results of FGM samples of (3, 5, 7) layers.

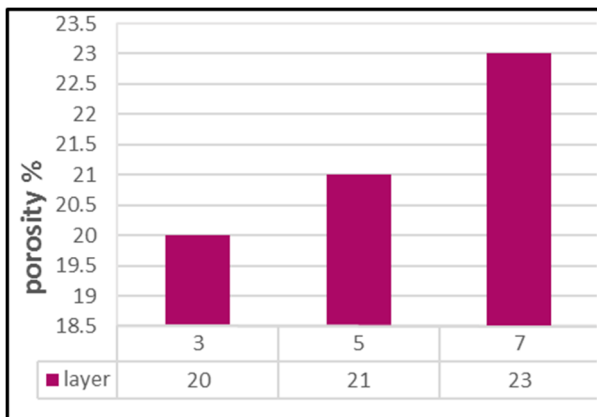


Fig. 4. Porosity results of FGM samples of (3, 5, 7) layers.

### 3.1.2. Lateral Shrinkage

Lateral shrinkage is one of the important parameter for estimating the quality of component gradation in a FGM structure. Figure (5) illustrates the effect of change of the percentages among the layers versus the number of layers of the sample sintered at 1100°C for 2 hours. Shrinkage showed an increase in FGM7 as compared with FGM3 and FGM5. The linear shrinkage obtained was an appropriate indicator of the functionality of the design.

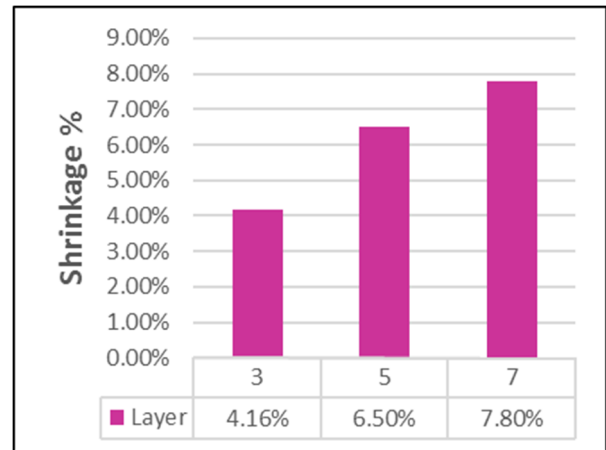


Fig. 5. Lateral Shrinkage of FGM samples of (3, 5, 7) layers.

### 3.1.3. Micro Hardness Test

Microhardness test was carried out to study the gradient of the mechanical property along the FGMs thickness. In spite of the fact that the phenomenon of hardness is in general is purely a surface property, which represents its resistance to indentation, but in numerous cases the value of surface hardness may be safely used to indication of the state of compactness and integrity of the bulk. The Vickers micro hardness value of FGM sample (3, 5, and 7) layers after sintering practices is presented in Figs. (6), (7) and (8) respectively. It is clear that as the Barium ferrite percentage increased; the hardness is increased. (FGM 3) seems to give graded hardness properties. Also it can be noted that the (FGM 7) layer 7 (100% BaM) and layer 1 (100% LiM) has the higher value of Vickers hardness as compared with (FGM3) and (FGM5) due to increment of density and compacting load.

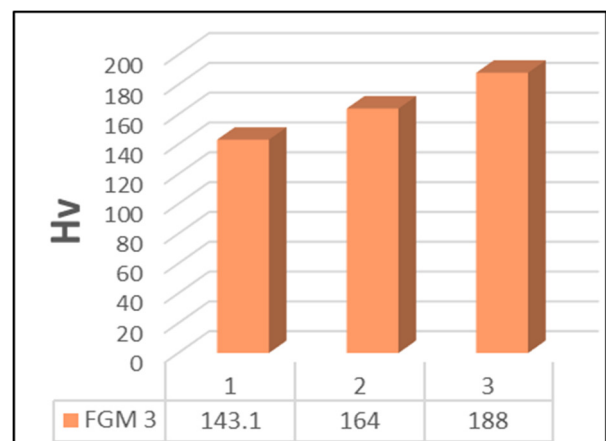


Fig. 6. Vickers hardness values for FGM 3.

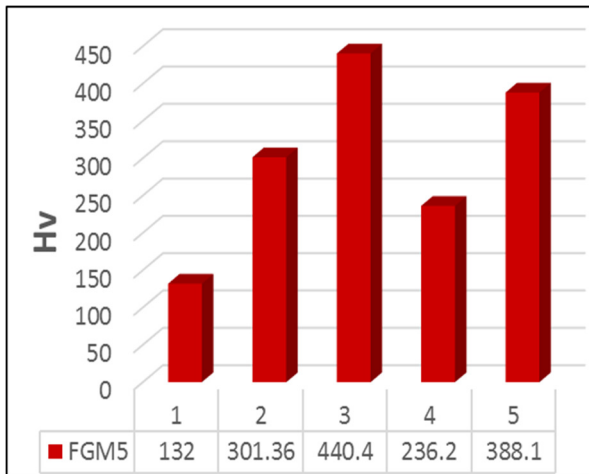


Fig. 7. Vickers hardness values for FGM 5.

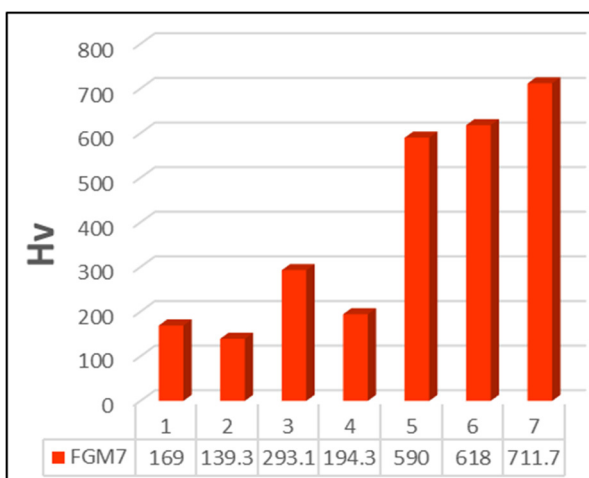


Fig. 8. Vickers hardness values for FGM 7

### 3.2. FE-Scanning Electron Microscopy (FESEM) Analysis

Field emission Scanning electron microscope (FESEM) is used to visualize the microstructure of functionally graded materials by scanning with high energy electron beams.

Fig. (9) Shows the microstructure of the fabricated LiM\BaM FGMs. It has three layers: the 1<sup>st</sup> layer (pure BaM) plate like structure with the average size (150-350)nm plus few spherical structure of size (150-200)nm, the 2<sup>nd</sup> layer mixed both plate of size lightly larger (250-400nm)average and spherical of size (400nm) while the 3<sup>rd</sup> layer (pure LiM) is spherical structure of 500 nm average size , respectively.

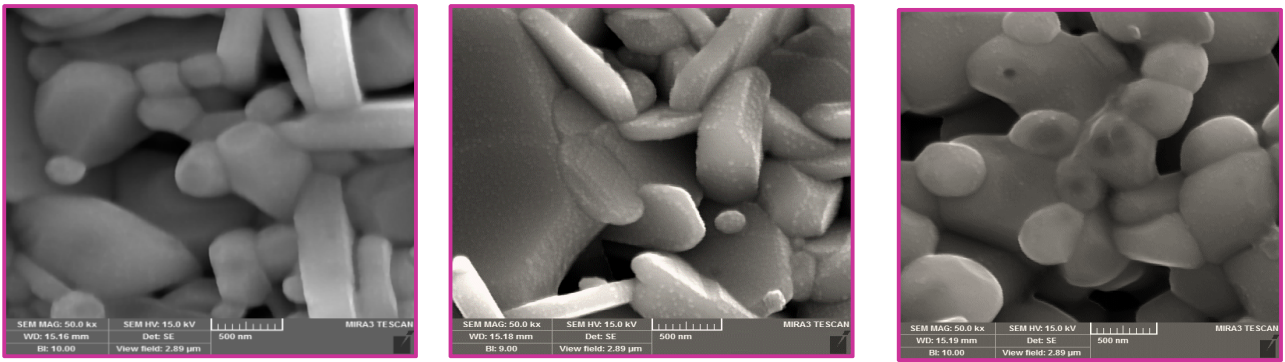
Fig. (10) Shows the microstructure of the fabricated LiM\BaM FGMs. It has five layers: the

1<sup>st</sup> layer (pure BaM) plate like structure with the average size (150-300) nm, 25LiM&75BaM, 50LiM&50BaM, 75LiM&25BaM (mixed both plate and spherical structure) with the average size (300,700,350) nm, respectively. The 5<sup>th</sup> layer (pure LiM) spherical less porous dense structure with average size (400-1500) nm, respectively.

Fig. (11) Shows the microstructure of the fabricated LiM\BaM FGMs. It has seven layers: the 1<sup>st</sup> layer (pure BaM) plate like structure with average size (250-350)nm, 35 LiM&65BaM plate like thickness range (350-400)nm, 50LiM &50BaM plate more thick (400)nm, 65LiM &35 BaM plate less thick (250)nm, 75LiM & 25 BaM nm spherical (250-1000)nm more dense less porous, 80 LiM &20 BaM spherical (350-1000)nm, the 7<sup>th</sup> layer (pure LiM) spherical structure (more growth, spherical large, less porous), respectively.

From the SEM images of 3<sup>rd</sup> layer FGM3 Fig.(8c), 5<sup>th</sup> layer of FGM5 Fig.(9e) and 7<sup>th</sup> layer of FGM 7 Fig.(10g) it can be seen the grain patterns exhibited totally spherical- like structure , a clear crystalline structure was also observed. Also it can be seen a large growth in size at the 3<sup>rd</sup> , 5<sup>th</sup> and 7<sup>th</sup> layer because of the remaining of one phase and disappearances of the other which use to be suppress the growth at the other layer. In contrast, as shown in SEM images of 1<sup>st</sup> layer FGM3 Fig. (8a), 1<sup>st</sup> layer of FGM5 Fig.(9a)and 1<sup>st</sup> layer of FGM7 Fig.(10a) the grain morphology appear totally plate -like shape which is clearly indicated the formation of barium ferrite. Barium hexaferrite nanoparticles with plate-like morphology is the best for the electromagnetic wave absorption application [9]. Also for the composite layer SEM images show the grain microstructure as a combination of spherical and plate like structure which is an evidence for the gradation in FGMs samples and resulting in properties variation.



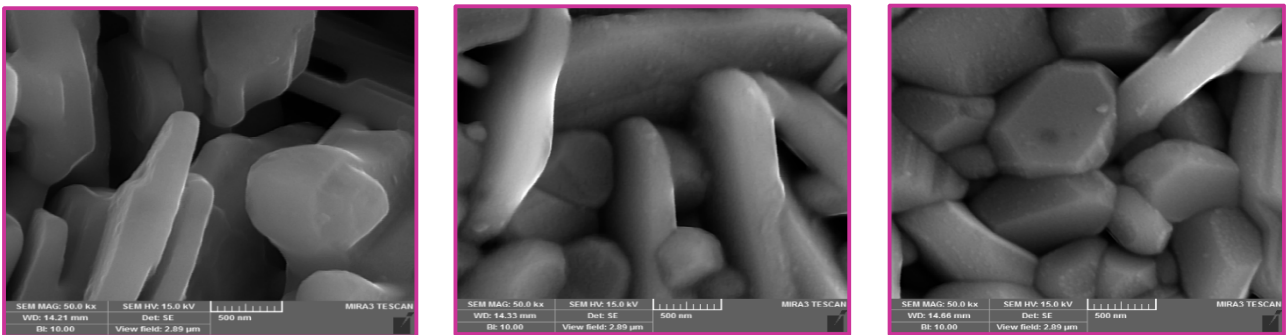


(a)

(b)

(c)

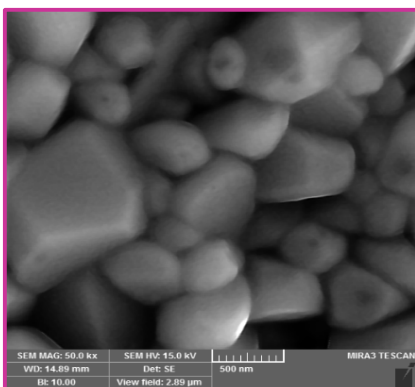
Fig. 9. FE-SEM of FGMs sample with 3 layers: a) first layer, b) second layer and c) third layer.



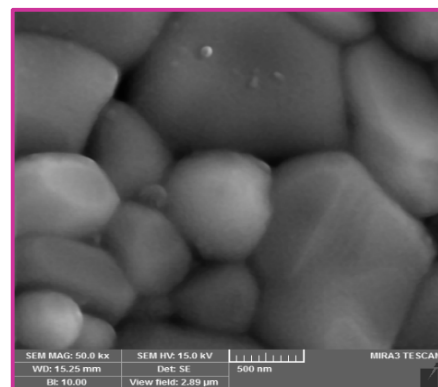
(a)

(b)

(c)



(d)



(e)

Fig. 10. FE-SEM of FGMs sample with 5 layers: a) first layer, b) second layer, c) third layer, d) fourth layer and e) fifth layer.

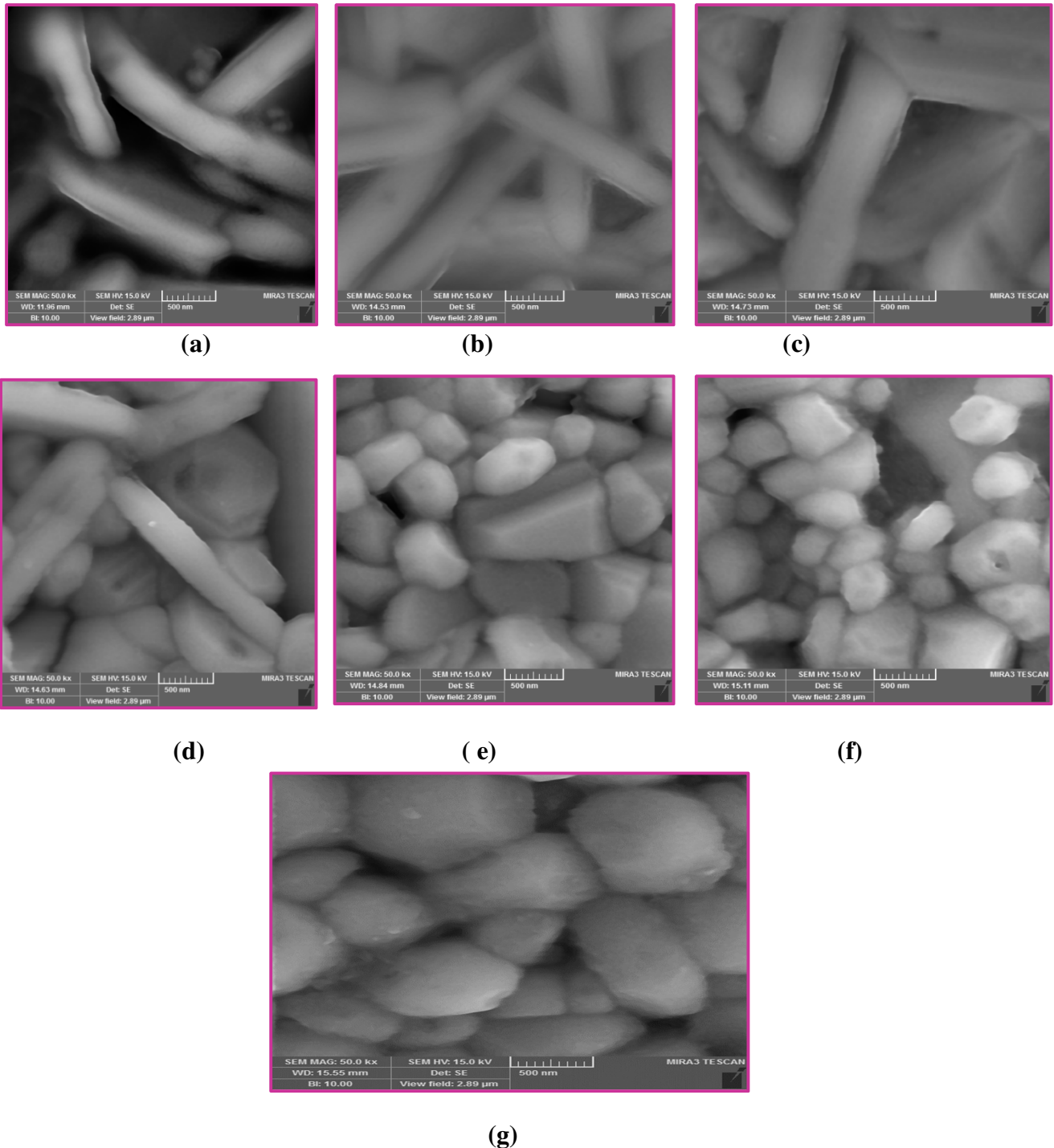


Fig. 11. FE-SEM of FGMs sample with 7 layers: a) first layer, b) second layer, c) third layer, d) fourth layer and e) fifth layer, f) sixth layer and g) seventh layer.

#### 4. Conclusions

Functionally graded BaM/LiM specimens have been fabricated at three different set of layer (3, 5 and 7) by powder metallurgy. Characterization of fabricated FGMs was carried out by FESEM which revealed gradation in microstructure from plate-like structure (hard ferrite) to spherical structure (soft ferrite). The result of density indicate the high homogeneity and good blending between the layers

of FGM led to increasing of density. The Vickers hardness showed higher value at FGM7 layer 7.

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## الخصائص الفيزيائية والمورفولوجية لمواد الفرايت صلب- ناعم المتدرجة وظيفيا

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### الخلاصة

المواد المتدرجة وظيفيا بمكونات سيراميك-سيراميك باستخدام تقنية تكنولوجيا المساحيق. وتم في هذا العمل تصنيع ثلاثة نماذج مختلفة من عينات المواد المتدرجة وظيفيا الى 3 طبقات , 5 طبقات و 7 طبقات. المكونات السيراميكية متمثلة بالفرايت الصلب ( فرايت الباريوم) والفرايت الناعم (فرايت الليثيوم) . جميع العينات تم تليبيدها بدرجة حراره ثابتة عند 100 درجة سيليزيه لمدة ساعتين وتم تشخيصها بتقنية الماسح الالكتروني. لقد تم قياس بعض الخصائص الفيزيائية لعينات المواد المتدرجة وظيفيا المصنعة تتضمن الكثافه الظاهرية, المضمخه, المساميه, الانكماش والصلادة. أوضحت النتائج ان الكثافة تزداد بأزدياد عدد الطبقات. الانكماش الخطي يعد من اهم العوامل لتقويم حدوث تدرج بالمواد داخل تركيب المواد المتدرجة وظيفيا. أوضحت صلادة فيكرز اعلى القيم عند عينة FGM7 , وأخيرا أظهرت صور الماسح الالكتروني تدرجا مجهريا داخل المنظومة من شكل صفائحي في الفرايت الصلب الى شكل كروي في الفرايت الناعم.