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Mnaouar Chouchane · Moez Abdennadher · Nizar Aifaoui · Fakher Chaari · Slim Bouaziz · Zouhaier Affi · Mohamed Haddar · Lotfi Romdhane · Abdelmajid Benamara *Editors*

Design and Modeling of Mechanical Systems - VI

Proceedings of the 10th Conference on Design and Modeling of Mechanical Systems, CMSM'2023, December 18–20, 2023, Hammamet, Tunisia - Volume 2: Materials Engineering and Manufacturing

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Preface

The tenth edition of the "International Congress Design and Modeling of Mechanical Systems" CMSM'2023 was held in Hammamet, Tunisia, from 18th to 20th of December 2023. The CMSM congress has been held in a Tunisian city every two years since its first edition in 2005. The CMSM congress brings together specialists from universities and industrial companies to present their recent research findings and to discuss and exchange research experiences with other attendees of the CMSM Congress. The CMSM Congress is jointly organized by two Tunisian research laboratories: The Mechanical Engineering Laboratory (LGM) of the National Engineering School of Monastir and the Mechanical, Modeling and Manufacturing Laboratory (LA2MP) of the National Engineering School of Sfax. The tenth edition of the CMSM Congress has been attended by about 250 participants who participated actively in the plenary sessions and in the sessions devoted to specialized topics. Five plenary conferences and about 156 papers and 17 posters have been presented during the three days of the congress.

This book is the sixth volume of the "Lecture Notes in Mechanical Engineering" series "Design and Modeling of Mechanical Systems". From the 173 papers and posters presented in the CMSM'2023, 91 papers are selected to be included in the two volumes of this book. The papers are classified into the following 8 topics:

1. Design and Analysis of Mechanical Systems
2. Numerical Modeling and Analysis of Structures and Systems
3. Mechanical Vibration Analysis and Applications
4. Industrial Engineering
5. Materials Science and Engineering
6. Composite and Bio-Materials
7. Surface Finishing and Coating
8. Manufacturing Engineering and Additive Manufacturing.

This first volume contains topics one to four. The second volume contains topics five to eight.

All the papers included in this volume have undergone rigorous reviewing by two or three reviewers. Authors have been provided by the comments of the reviewers and requested to submit revised papers. The review process contributed significantly to the improvement of the quality of the papers included in this volume. The editors would like to thank all the authors for submitting their recent research work to the CMSM'2023 congress and for considering the comments of the reviewers to revise their papers. The hard work of the reviewers is also highly appreciated. The editors are also grateful to the

organizing committee of the CMSM'2023 and to the editing team of Springer publication for providing support for the publication of this proceedings.

December 2023

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- Please indicate a conference webpage address and/or a Call for papers.

https://cmsm.tn/CMSM2023/

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Composite and Bio-Materials

Materials Science and Engineering

Evaluation of Parameters for Magnesium Fabrication by Powder Metallurgy Route

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Abstract. The key benefits of magnesium and its alloys are their high biocompatibility and specific strength. Powder metallurgy is a contemporary method for the preparation of materials based on magnesium. The micro-hardness of pure magnesium (Mg) samples is evaluated in this study after they were produced through the powder metallurgy process. Magnesium powder's purity and microstructure were examined using electron microscopy and x-ray diffractometry. The cold compaction of powdered magnesium was examined. At laboratory temperature, magnesium powder with a mean particle size of 30 μm was compressed using pressures of 400, 450, 500, 550, 600, and 650 MPa. The impact of compacting pressure was examined using %porosity and green density. It was found that a pressure of 650 MPa produced the best density of 1.715 gm/cm^3 and %porosity of 1.323. The sintering process was conducted at three different temperatures (455, 525, and 585 °C) and three different sintering time (30, 45, 60) min. It was found that 525 °C for 30 min produced the best results, with a density of 1.725 g/cm3, porosity of 0.75%, and micro-hardness of 97.77%.

Keywords: Evaluation · Magnesium · Powder metallurgy · Sintering process · Microhardness

1 Introduction

With a density of 1.74 g/cm^3, magnesium (Mg) is one of the light metals and is found in large quantities in both the sea and the crust of the earth. Mg has high strength-to-weight ratios due to their low density. Because of this wonderful quality, it is appealing for lightweight [1–3]. For instance, Mg and its alloys are good choice for reducing weight for carrying convenience in customer electronics and tools for power; in the automotive industry, weight reduction through the use of Mg components can significantly reduce CO_2 (Carbon dioxide gas) emissions and fuel consumption [1]. Since 1999, the global production of Mg and its alloys has been rising steadily. Cars built in Germany have already made use of some Mg components [1]. Due to their appropriate mechanical

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properties and good biocompatibility, Mg and its some alloys are also utilized by means of biodegradable materials [4–10]. Mg and its alloys have attracted a lot of attention by means of potential replacements for conventional orthopedic implantation constituents in recent years [11–13]. What's more, these substances are entirely absorbed by the body once bone tissue regenerates since they are biodegradable [14]. Additionally, it was observed that Magnesium has effection on lipid profile [15]. The synthesis and characterization of pure Mg produced using the cold powder metallurgy method is the main goal of this work. The micro hardness of sintered Mg specimens, their density and porosity have been studied.

2 Material and Experimental Methods

The mean size of the Mg powder particle used in this study was approximately 30 μm, and it has an irregular blocky shape as illustrated in (Fig. 1). The purity of base Mg powder was 99.8%. It was provided by Jingan Chemicals & Alloy Company - China.

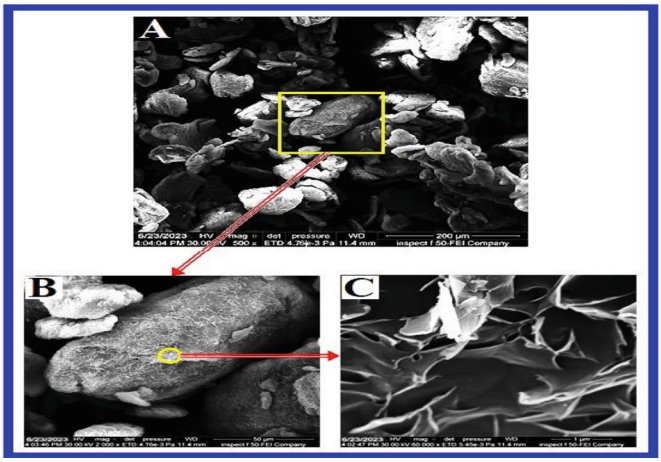

Fig. 1. FESEM Image for pure magnesium powder at different magnification powers

Lab XRD-6000 Shimadzu- Japan XRD machine was used for phase identification analysis for Mg powder. XRD has been used to ensure that the supplied powder is Mg powder and does not contain any other impurities as clearly displayed in (Fig. 2).

A 304 stainless steel vessel was charged with Mg powder and 11 mm diameter balls made of chromium iron with a ratio of weight 1:10, respectively. The powder was milled for three hours at 121 rpm with aid of the ball milling machine that was designed and manufactured for this purpose. The balls Vickers micro-hardness (HV) was (855) evaluated by Metkon micro-hardness device with 500 gm applied force. Alloy steel die and punch and other components shown in (Fig. 3) were used to create cylindrical samples with 15 mm diameter and with a height suitable for each test.

At room temperature, compaction of the Mg powder into compacts was achieved by applying varying uniaxial pressures of (400, 450, 500, 550, 600, and 650) MPa.

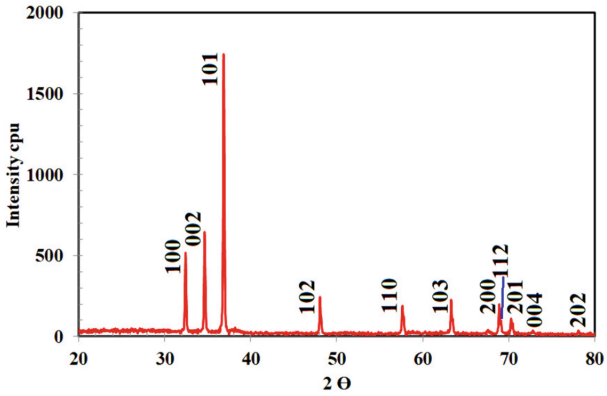

Fig. 2. XRD Analysis diagram for pure magnesium powder

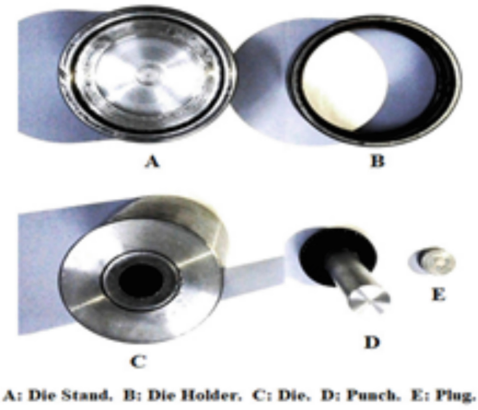

Fig. 3. Main parts pressing tool.

Green samples density (ρg) considered by as stated Eq. (1) [14] the mass of samples was weighted by electronic type balance with 0.1mg accurateness. The volume of samples was measured with the aid of determining the major dimensions.

$$Pg = Mc/Vg \tag{1}$$

Percent porosities (%P) are measured according to the Eq. (2) [14].

$$\%\mathrm{P} = (1 - \rho g/\rho \mathrm{Th}) \times 100 \tag{2}$$

Next, from the start of the sintering to room temperature, the samples are existed in an electric furnace of CARBOLITE-UK type while an argon gas stream is continuously applied. For thirty minutes, samples was soaked at the appropriate temperatures (455, 525, and 585 °C), several samples at each temperature. The rate of heating is set at 10 °C/min. Then samples were allowed to cool inside the furnace gradually to room

temperature. The samples' parallel faces was wet ground with the utility of SiC emery papers with grits of 240, 600, 1000, 2000, and 3000, polished with a 5 μm suspension of alumina solution, cleaned with distilled water, and dried in a oven at 120 °C for 20 min. Vickers micro-hardness for sintered compacts (SCs) was determined using the same technique described above. For microstructure analyses, optical microscopy Italy made invert microscope - was employed.

3 Results and Discussion

Determining the best pressing pressure for Mg samples preparation is crucial. Pressing pressure and green density were found to be directly correlated (Table 1). Greatest (ρg) result was under the highest applied pressure (650 MPa) with the maximum 1.715 g/Cm^3 was achieved. Figure 4 illustrates how density and compression pressure are proportionally related. Hence the decision was that 650MPa is the ideal applying pressure. As a result, it was used later in the preparation of all samples.

Table 1. Density and Porosity of pure magnesium against applied pressure

Sample No	Pressing Pressure MPa	Green Density g/cm^3	Porosity %
1	400	1.58	9.09
2	450	1.615	7.077
3	500	1.622	6.674
4	550	1.681	3.28
5	600	1.699	2.244
6	650	1.715	1.323

On other hand the porosity decreased by increasing of the compacting pressure and the powder particle's deformation increased with increasing compaction pressure. The best porosity (1.323%) obtained at 650 MPa. Figure 5 illustrates how % porosity and compression pressure are related.

The best density value of 1.725 g/cm^3 (that is nearest to the theoretical density of Mg, % porosity of 0.75% and microhardness of 97.77 were obtained at a sintering temperature of 525 °C and 30 min of sintering time. (Table 2) displays the density, % porosity and Microhardness calculated at each sintering temperature and time.

Optical microscope photo in Fig. 6 A and B for non-etched microstructure is discovered the how the porosity was restricted at Mg particles boundaries. At some positions the powder particles boundaries are clearly shown while at other positions the boundaries between the nearby particles are partially disappeared due to the diffusion process that occurred at sintering.

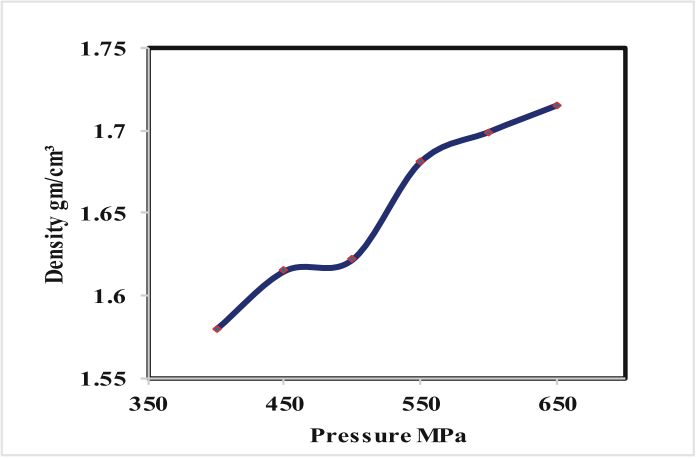

Fig. 4. Relationship between green density and applied compaction pressure

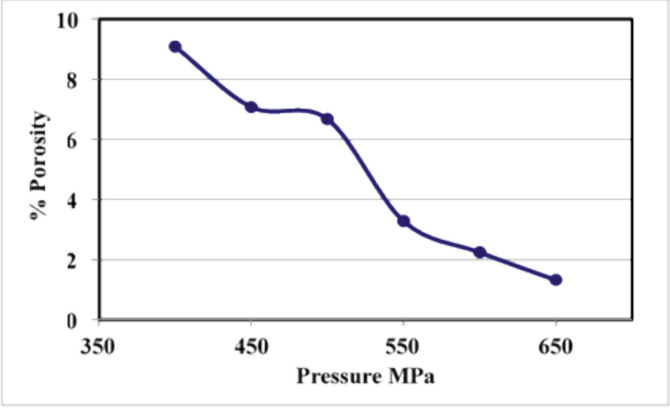

Fig. 5. Relation between % porosity and applied pressing pressure

Table 2. Density, %Porosity and Microhardness of pure Mg at each sintering temperature and time.

Pressure MPa	Temperature °C	Times min	Density g/cm3	Porosity %	HV
650	455	60	1.715	1.32	64.47
650	525	30	1.725	0. 75	97.77
650	585	45	1.695	2.5	80.56
650	455	30	1.722	0.92	75.46
650	525	45	1.7247	0.765	90.52
650	585	60	1.684	3.1	79.68
650	455	45	1.721	0.98	73.27
650	525	60	1.7246	0.77	87.14
650	585	30	1.708	1.37	86.9

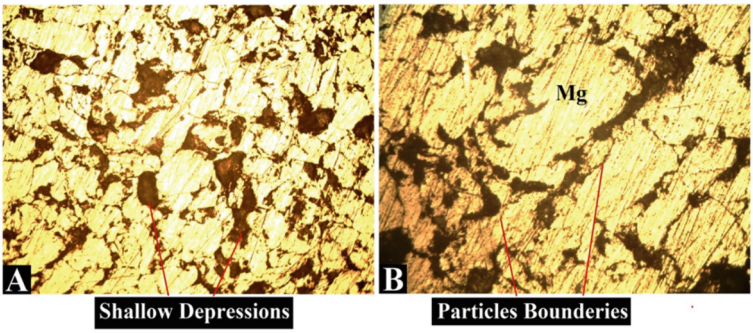

Fig. 6. A and B Microstructure of the Mg sample sintered at 525 °C 500X

4 Conclusion

1. This investigation is accomplished efficaciously from the view point of fabrication of Mg compacts initially for the reason of the capability to protecting the compacted samples from impurity that may be imported from powder metallurgy processing beginning from milling to sintering process.
2. The presence of the porosity inside the sintered samples was with very low value that is strong evidence to the success of pressing and sintering processes.
3. All three factors have a distinct impact on the overall quality of the result.
4. Maximum micro-hardness which extended to (~ 98 HV) is comparable to its value for cast Mg products.

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Study of the Effects of Gamma Irradiation on the Mechanical Properties of NBR Material

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Abstract. This article presents an experimental study of the mechanical properties of nitrile-butadiene rubber (NBR) when irradiated with gamma rays. NBR was irradiated with gamma rays at different absorbed radiation energy doses (0, 30, 45, 60, 75 and 90 kGy). Tensile experiments and hardness test analyses show an improvement in the elastic behavior of NBRs and a decrease in their plastic behavior with increasing absorbed radiation energy doses. Scanning electron microscopy (SEM) shows the NBR surface layer to be porous and cracked as a result of gamma irradiation. The experimental study was completed by a numerical simulation with Abaqus software using hyperelastic models (Mooney Rivlin model, Ogden model, Yeoh model, Arruda-Boyce model and Neo-Hookean model). The simulation uses input data obtained from traction results. Curves of stress-strain for pristine and irradiated samples, obtained from numerical and experimental studies, were compared. Parameters of the hyperelastic deformation energy function are computed for each of the five models. So, the Ogden model was found to produce the most accurate curve, with a mean square error less than 0.5%. The Ogden model is therefore the most appropriate for simulating the mechanical behavior of irradiated nitrile-butadiene rubber. The results obtained provide a good basis for describing the performance of this material under gamma rays.

Keywords: Nitrile butadiene rubber · gamma irradiation · Abaqus · hyperelastic models · tensile test

1 Introduction

Nitrile-butadiene rubbers (NBR) are used over a wide temperature range and are known for their cost-effectiveness, high oil and fuel compatibility, good elasticity and excellent adherence [1–4].

The mechanical properties of NBR rubber can be affected by gamma irradiation. Indeed, tensile strength, modulus of elasticity, elongation at failure and hardness are all found to modify as irradiation dose γ increases [5–7]. Numerous researchers [8, 9] have studied the effect of gamma irradiation on elastic modulus, tensile strength and hardness.

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They reported that the behavior of rubber when irradiated is complex. Therefore, it is necessary to use simulations to partially minimize or avoid experimental testing.

This article examines the mechanical behavior of NBR exposed to different doses of gamma radiation. Uniaxial tensile and hardness measurements were first carried out on pristine and irradiated NBR samples. The results are shown and commented on. Next, morphological properties were explored by scanning electron microscopy (SEM). Finally, a simulation was carried out using Abaqus.

2 Materials and Methods

In the present research, we used NBR (nitrile-butadiene rubber) marketed under the name of the product Europrene® N 3345. Several sheets of the material were irradiated with gamma rays at different doses (0 to 90 kGy). The effect of absorbed radiation energy doses on the mechanical properties of NBR was studied using tensile and hardness measurements. Tensile tests were carried out at room temperature on samples manufactured in accordance with ASTM D412 type C, using a universal machine (LLOYD LR5K). Hardness measurements were performed according to ASTM D 2240, using a Shore A hardness tester. Scanning electron microscopy (SEM) was used to visualize the effects of gamma irradiation on the morphology of the NBR material.

3 Results and Discussion

Results of tensile tests performed on samples of virgin and gamma-irradiated NBR, at absorbed radiation energy doses ranging from 00 to 90 kGy, are presented in Table 1. Figure 1 shows the corresponding stress-strain curves.

Table 1. Tensile properties of irradiated NBR samples.

Gamma dose (kGy)	00	30	45	60	75	90
Elastic modulus (MPa)	13.15	13.26	14.67	17.50	18.06	18.01
Tensile strength (MPa)	4.93	4.72	4.51	4.63	4.73	5.02
Strain at break (%)	243	233	219	218	217	224
Strain at ultimate strength (%)	232.46	224.78	211.45	201.47	198.17	215.96
Stress at 100% strain (relative values %)	101	97	96	101	103	107
Stress at 200% strain (relative values %)	101	98	97	102	103	107
Toughness (106 J/m3)	8.05	7.23	6.64	6.54	6.6	6.8
Crosslink density (10-4mol/cm3)	2.73	2.77	2.65	3.05	3.17	3.38
Strain at break (%)	243	233	219	218	217	224

Figure 2 shows the influence of irradiation on the modulus of elasticity of NBR material. It is clear that the stiffness of NBR increases with increasing irradiation dose.

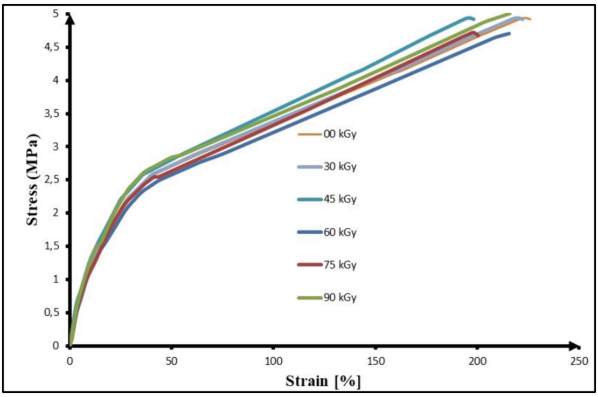

Fig. 1. NBR stress-strain curves for different doses

In fact, an increase in Young's modulus of up to 37 is due to new cross-linking reactions and a reduction in distance of atomic separation in irradiated specimens [1, 8–10]. In addition, irradiation significantly affected the tensile resistance of the material due to crosslinking/degradation [11]. The variation in tensile resistance with gamma irradiation dose is shown in Fig. 3. It can be seen that tensile strength varies slightly with increasing gamma dose. It gradually decreases to a minimum value at an absorbed radiation energy dose of 45 kGy, then slowly increases again. This is due to modifications in polymer chain scission and increased cross-linking density resulting from high absorbed radiation energy doses.

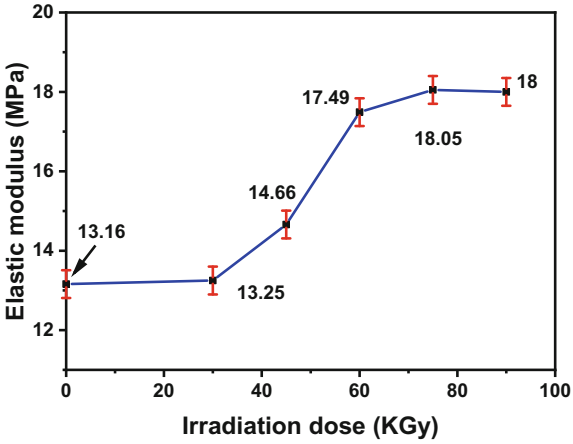

Fig. 2. NBR elastic modulus at different γ-doses.

The effect of radiation dose on NBR failure was investigated by examining the evolution of strain at failure versus absorbed radiation energy dose. The results show that strain at failure decreases with increasing absorbed dose. Indeed, a rapid decrease

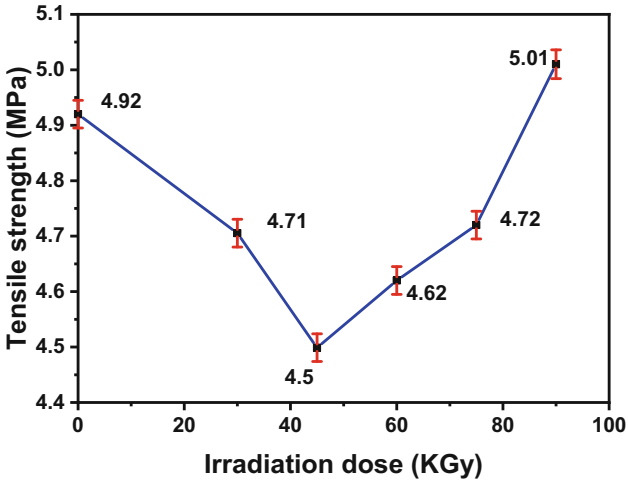

Fig. 3. Tensile strength as a function of irradiation dose

is observed at doses below 45 kGy, with a gradual decrease at higher doses (Fig. 4). It reaches 16.9% at 90 kGy. This can be explained by the supplementary bonding of filler and polymer due to the elevated free-radical formation [12]. It is also due to additional cross-linking reactions during irradiation [13].

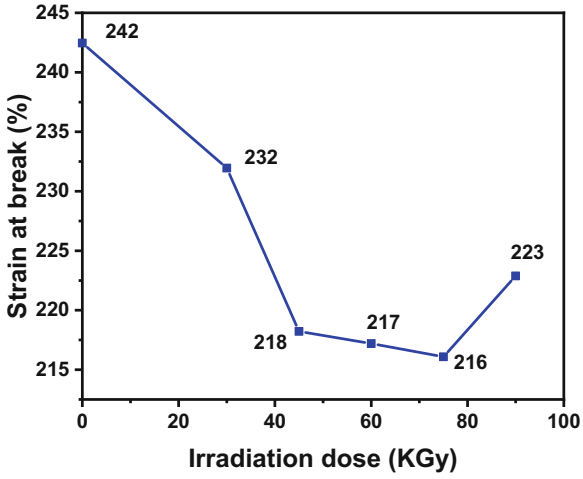

Fig. 4. Strain at break versus absorbed dose

A material's toughness is defined by the energy of deformation at failure per volume (J/m^3). It corresponds to the material's capacity to deform plastically without breaking. The toughness of virgin and gamma-irradiated NBR was calculated and plotted versus gamma dose (Fig. 5). Toughness decreases progressively with increasing gamma dose.

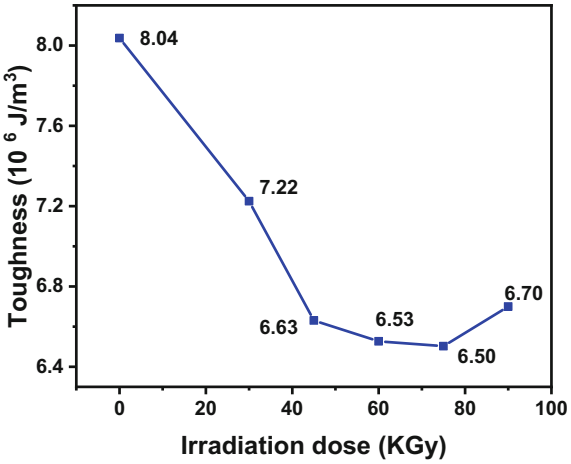

Fig. 5. Toughness versus absorbed dose

The effect of absorbed radiation energy dose on material hardness was examined by means of Shore A hardness measurements. The results presented in Table 2 and Fig. 6 indicate an increase in NBR hardness with increasing gamma dose. This is coherent with the observation made above for the elastic modulus parameter, and shows that NBR material is becoming stiffer with rising irradiation dose.

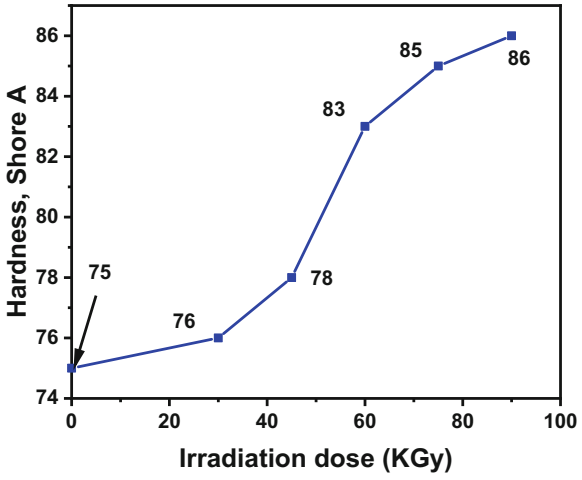

Fig. 6. NBR hardness as a function of γ-irradiation dose

The influence of gamma rays on the morphology of the NBR was examined by scanning electron microscopy (SEM). Figure 7 shows the surface morphology of virgin and irradiated specimens. Visibly porous surfaces and cracks in the NBR surface layer are the result of gamma irradiation. Polymer fibers randomly arranged in the pristine

Table 2. Hardness shore A of irradiated NBR samples.

Absorbed radiation energy dose (kGy)	00	30	45	60	75	90
Hardness (Sh-A)	75	76	78	83	85	86

specimen. In the irradiated samples, however, the fibers disappeared as pores formed on the surface. The result could be that the polymer fibers agglomerate to form semi-compact zones and pores.

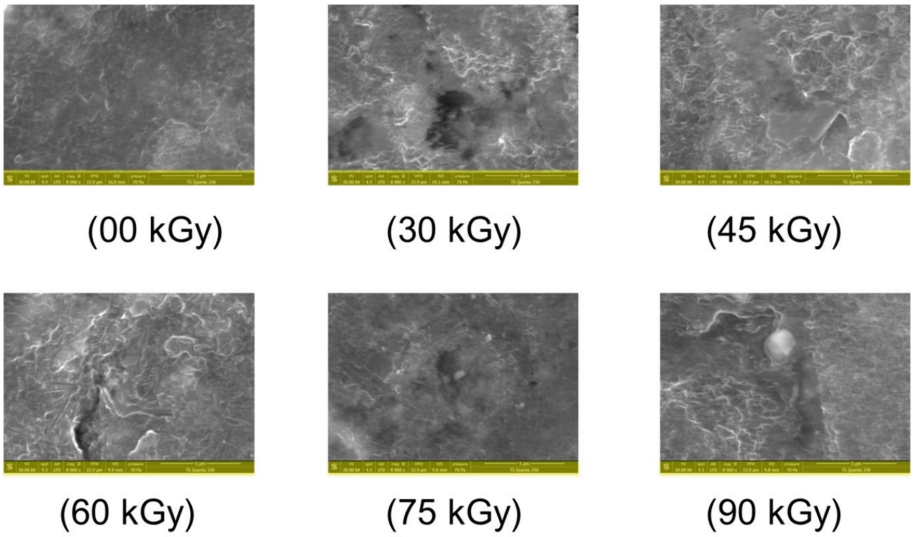

Fig. 7. SEM images.

4 Numerical Study

The principal purpose of the numerical analysis was to identify a suitable model to describe the hyperelastic properties of NBR rubber under gamma irradiation.

The tensile behavior of the material, before and after irradiation, was simulated based on the assumption of a hyperelastic material property model, using as input data those found by uniaxial tensile tests. The models employed (Mooney Rivlin, Ogden, Yeoh, Arruda-Boyce and Neo-Hookean models) express rubber stress and deformation as functions of strain energy.

The numerical study uses ABAQUS software to calculate the non-linear deformations of NBR material before and after irradiation. After selecting the hyperelastic models mentioned above, the results were assessed by reanalyzing the experimental data, verifying model stability, establishing stress-strain curves and identifying material-specific constants and best-fit.