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Study on Tablet conversion by pressure-less sintering method on the thermoluminescent dosimetric response of Beta Tricalcium Phosphate

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HIGHLIGHTS

- Conversion of commercial β-TCP powder into tablets by pressure-less sintering method.
- Comparison of TL response of tablet and powder samples in the dose range of 20 to 1500 Gy.
- Investigating the effects of fading, reproducibility, sensitivity, formation of the peaks, and microhardness measurement.
- Increasing the grain size by turning it into tablets.
- Increasing probability of first-order kinetics with tablet conversion.

ABSTRACT

In this research work, commercial beta-tricalcium phosphate powder is converted into tablets by pressure-less sintering method. Thermoluminescence responses of tablet and powder samples in the dose range of 20 to 1500 Gy have been compared and effective factors in tablet conversion such as mass in the range of 30 to 60 mg, force between 1 to 3 N, concentration of granulating solution and tablet diameter in the range of 0.4 to 15 mm are investigated based on the results of dosimetric response and tablet hardness. The results show that by turning into tablets, the grain size increases, and the possibility of the first-order kinetics increases by the conversion of powders into tablets. It is possible to achieve a better dosimetric response than the it's powder by applying suitable conditions for turning into tablets; Also, the diameter of the sample can affect hardness, and it is better to make the tablets with a smaller size. Based on the results obtained from fading, reproducibility, sensitivity, peak shaping of the glow curve, and microhardness measurement, it can be seen that the samples that have been subjected to less pressure perform better and in order to achieve the desired results of converting to TLD dosimetry tablets, it is better to use more mass for tablets if more pressure is needed.

KEYWORDS

Dosimetry
Thermoluminescence
Pressureless Sintering
Calcium Phosphate

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1 Introduction

The irradiation process has been widely investigated during the last 50 years. During these years, the effect of radiation on maintaining the quality of all types of food has been investigated and the limitations of this method have been identified (Munir and Federighi, 2020). One of its most important uses is in the field of agricultural products This process is used to optimize the properties, repel pests, and also increase the storage time of products. To achieve the best results in various radiation processing applications, doses in the range of 10 Gy to 50 kGy are needed (Eichholz, 2003). When the required dose is given to the target sample, the desired result is obtained. If the absorbed dose in the sample is less than the specified value, it is not effective and if the received dose is more than the specified value, it can have destructive effects on the sample. Therefore, it is very important to measure the absorbed dose in the samples. Therefore, it is tried to use dosimetry systems with high accuracy and precision in measurement (Munir and Federighi, 2020). Different types of dosimeters including gas ionization chambers, thin films, and solid and liquid dosimeters have been used. According to the dosimetry ranges, there are not many choices to cover the entire dosimetry range of agricultural products. Therefore, the need for a reliable, cheap, easy-to-build dosimeter and convenient reading system is nec-

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essary for use in daily dosimetry of agricultural products (Adachi et al., 2004; Kashian et al., 2022). The thermoluminescence is a suitable and well-known method for passive dosimetry. Each of the thermoluminescence dosimeters may have limitations in dosimetry range, saturation point, energy dependence, ease of access, effective atomic number, peak temperature, preparation, manufacturing, etc.

Thermoluminescence (TL) is the light emitted from an insulator or a semiconductor, when it is heated after irradiation against ionizing rays (Alvarez et al., 2014; Shafaei et al., 2016). Thermoluminescence has a glow curve consisting of one or more peaks. The output glow curve is the electric charge of the reader in terms of temperature (Alencar, 2009).The temperature peak of the glow curve has the highest intensity and usually has high stability and is not affected by fading effects. The temperature peak of the glow curve has the highest intensity and usually has high stability and is not affected by fading effects (Mazhdi et al., 2012). The basis for using thermoluminescence dosimetry is that the amount of TL light is proportional to the amount of irradiated absorbed dose (Shafiqah et al., 2015).

When the trapped electrons jump to the conduction band by thermal energy, they have two kinds of chances to jump down. One process is re-trapping in the same type of trap and the other is recombination with the hole which is accompanied by TL light emission. When the probability of retrapping by energy can be neglected, the glow curve has a narrow peak with a rapid recombination process, as shown by Randall and Wilkins in 1945. Otherwise, if the retrapping process dominates, recombination with holes is suppressed and the curve has a wide peak explained by Garlick and Gibson in 1948. These two descriptions are called the first-order and second-order kinetics, respectively. General order kinetics is also presented to achieve a suitable analytical continuum and is placed between these two kinetics, which was presented by May and Partrich in 1964 (Alam and Bauk, 2010).

Sulfates, sulfides and fluorides of earth elements and alkaline materials are widely studied and used in TL dosimetry. Considering that calcium phosphates are equivalent to bone minerals, these materials can be used as thermal dosimeters (Shafaei et al., 2015). Due to the properties of these materials, they have recently been used in retrospective dosimetry (Daneshvar et al., 2019b). Among the calcium phosphates, β-TCP has many applications in medical fields, such as artificial bone and humidity sensors with high temperature and has great thermal stability. Also, this substance can be a suitable host to replace impurities and be used for photoluminescence and thermal applications (Nakashima et al., 2005). The reasons for the research work on this material in TLD dosimeters can be the following (Daneshvar et al., 2019a, 2020b,a; Dodd and Massengill, 2003; Sadat-Shojai et al., 2013; Taghipour et al., 2023, 2022a,b):

1. Appropriate dosimetric response of calcium phosphate samples that have been previously tested, especially in high dose irradiation.
2. Existence of variation in response to high and low doses with a change in Ca/P ratio (calcium to phosphorus) in different structures of this material.
3. The appropriate ability of this material to host and add impurities for increasing the TL response.
4. The equivalence of this type of substance with bone minerals.
5. Suitable conditions for synthesis due to ease of access to materials and equipment and variety in synthesis methods.
6. Existence of suitable experience for dosimetry measurement by TL, PL and ESR methods.
7. Existence of limitations and obstacles such as dosimetry range, saturation point, fading effects, etc. in the use of commercial dosimeters (Dorozhkin, 2017; Madhukumar et al., 2007).

The works is carried out in Iran in the field of thermal dosimetry were on commercial dosimeters TLD-100, GR-200, TLD-400, TLD-500, TLD-600 and TLD-700. In the meantime, studies have been done on the powder state of these dosimeters and the effect of various impurities. Investigations have also been conducted in the field of materials such as ZnO, ZnTe, BeO and CaF_2 contaminated with various impurities. Several studies have been conducted on the manufacture of GR-200 dosimeters by solid state method (melting) and then turning them into tablets using a pressure less sintering method (hydraulic press). Similar work has been done for CaF_2. Performing tests such as uniformity, sensitivity, linearity, reproducibility, the lowest measurable dose, inherent dose and residual dose have been carried out on the GR-200 dosimeter made in the country (Abbasisiar et al., 2018; Harooni and Akbari, 2022; Alipour et al., 2016; Baradaran et al., 2022; Choopan Dastjerdi and Mokhtari, 2020; Danaei et al., 2021; Ghovvati and Manouchehri, 2014; Harooni et al., 2022; Hosseini Pooya and Dashtipour, 2018; Mehnati et al., 2019; Moghadam et al., 2016; Panjnoush et al., 2009; Pourshahab et al., 2013; Sadeghi et al., 2022; Torkzadeh and Jafarizadeh, 2015).

Recently, compression using pressure-less sintering methods, hot pressing and spark plasma sintering processes has been developed a lot (Munir and Federighi, 2020). Sintering without pressure is the sintering of compressed powder (sometimes at very high temperatures depending on the powder) without applying pressure. In more traditional methods of hot pressing, simultaneous application of pressure and temperature causes changes in density. In pressure-less sintering method, there is no density change (Sripathy and Gupta, 2021). Until 1970, ceramics were only compacted using the hot press method. Due to the extreme pressures required for condensation, the pressure-less sintering process was considered unlikely or impossible until the late 1980s. Then, by comparing the results of this method with the hot-pressing process, pressure-free sintering was developed for pure ceramic parts with complex geometries, which reduced costs. Comparison of the pressure-less sintering

process with hot pressing showed that the first method reduced the costs and therefore this process was developed for pure ceramic parts with complex geometries (Munir and Federighi, 2020).

The use of powder causes non-uniform distribution of the thermoluminescent material on the reader tray, it can also cause contamination of the PMT, its filter and the reader tray, and therefore causes the creation of a background signal at the output of the reader. Another disadvantage of using powder is the creation of an unwanted signal due to the mechanical stress between the thermoluminescence materials during reading, and thus it causes an increase in the detection threshold and makes errors in dose determination (Furetta, 2010). These observations depend on the amount of dose and are less in the high dose range and can be ignored. The main innovation of the present work is obtaining the technical knowledge to convert calcium phosphate powder samples into tablets by pressure-less sintering method, and then thermoluminescence dosimetry tests are performed.

2 Material and Methods

In this article, the dosimetry of β-TCP samples in the form of powder and tablets produced from them has been investigated. β-TCP powder was purchased commercially from Merck company. The samples were read using a Harsha 4500 reader. This reader is a cost-effective device for measuring absorbed radiation dose.

The dosimeters that are read on this device can be in the form of powder, tablets or cards (ASTM, 2006). The samples were irradiated using a GC-220 Gamma Cell device available in the Irradiation Systems Laboratory of the Radiation Application Research Institute. Calibration of the source is performed periodically by Fricke reference dosimeter (ASTM, 2006). The samples have been irradiated in the range of 20 to 1500 Gy. In this article, Merck's beta tricalcium phosphate is abbreviated as B(M). In Table 1, the notations made for the changes of different quantities are presented separately.

Table 1: Changes in different quantities for calcium phosphate tablet samples.

Quantity	Notations
Change in concentration of PVA solution	Like 1, 1.5, 0.6 and 0.7 PVA
Not sieved sample	west
Force (N)	t
Tablet mass (mg)	30, 40, 50 and 60

2.1 Preparation of tablets by pressure-less method

To produce a quality, smooth and unbreakable tablet, it must be possible to convert them into a granulated powder. These particles should have a high density and a high adhesion between the powder particles. It does not have the property of sticking to other surfaces such as the container or the parts involved in the tablet press, such as the walls of molds or punches. There should be proper fluidity between the particles so that they can easily fill all the empty space in the mold completely. The method of preparing tablets is to prepare a PVA solution, to impregnate the powder with this organic adhesive, to keep the powder and adhesive for a 24-hour period, or in other words, aging, sieving and tableting using a hydraulic press. For some samples, gluing or sieving has not been done. Also, the concentration of PVA solution is also variable and the change in this quantity has been investigated for some samples. PVA is a material that is used as an adhesive for ceramic materials. 6% PVA solution can be made to obtain liquid glue. This work was done for 1 hour on a magnetic stirrer at 1500 RPM and at a temperature of approximately 70 °C. The required amount of PVA to obtain a sticky powder is approximately 2% of the powder mass. Then calcium phosphate ceramic powders are impregnated with PVA organic glue. This composition is wrapped in metal foil and remains in this state for 24 hours. Then the viscous powder is sieved. Powder sieving is done in order to granulate the powder.

Typically, granulation involves the accumulation of fine particles in larger grains. Granulation is needed to improve the flowability of the powder and also to improve the mechanical properties of tablets. In the pressure-less sintering method, tableting is done using hydraulic presses. The tools required for this work are mandrels and matrix, which are made in different diameters. For this purpose, the hydraulic presses available in the Van de Graff laboratories of the Physics and Accelerator Research Institute and in the Dosimetry and Radiological Evaluation Laboratory of the Radiation Application Research Institute have been used. Tableting has been done with mandrel and matrix of different diameters of 1.5 cm, 4 and 6 mm. The approximate thickness of the tablets is 1 mm, the force on the tablets was in the range of 1 to 3 N.

2.2 Heat treatment

After the tablets are prepared using pressure-less sintering and hydraulic press, they should be subjected to heat treatment. Programmable furnaces are needed to apply heat treatment. The furnace is a box type. Heat treatment is primarily done to remove PVA organic glue. This work is done at a 450 °C temperature and 1 hour holding time. The final temperature for β-TCP material is equal to 800 °C. The graph of the heat treatment profile for β-TCP sample is shown in Fig. 1.

2.3 Irradiation of samples

The samples were irradiated using the Gammacell-220 Co-60 source available in the dosimetry laboratory of the Radiation Application Research Institute with a dose rate of approximately 1 $Gy.s^{-1}$. The irradiation range for most of the samples was 20 to 800 Gy and some samples were irradiated up to 1500 Gy.

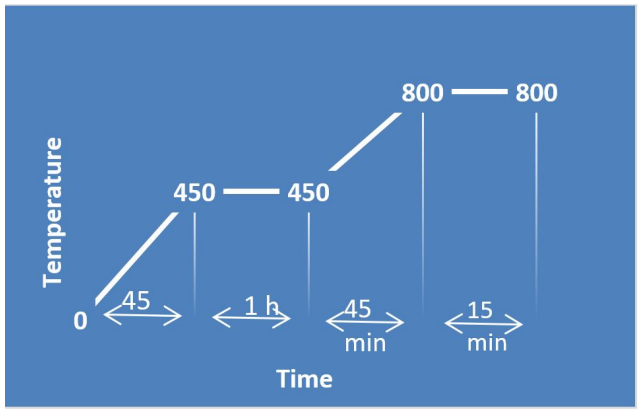


Figure 1: Heat treatment after pelletizing β-TCP sample.

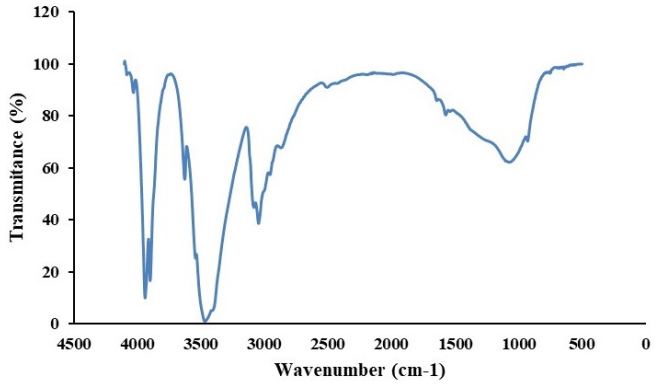


Figure 2: Output results of FTIR analysis.

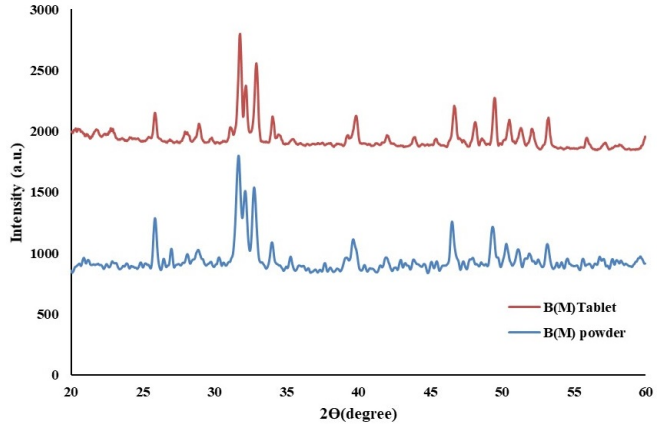


Figure 3: Output results of XRD analysis.

2.4 Reading samples

Due to the large response value of the samples, filter number 10 was used to avoid damaging the reader. Commercial readers are usually designed to measure as little as possible. There are situations in which light measurement with high intensity is needed, for example, high dose dosimetry at the industrial level or ultra-sensitive detectors. Different filters are used to improve measurements and prevent degradation. Two filters with numbers 10 and 100 can be used on this device. Filter 10 means reducing the light intensity by 10 times less. The samples are also read before irradiation and the background value is subtracted from the total read value of the irradiated samples.

3 Discussion and results

3.1 Analysis

3.1.1 FTIR

Figure 2 shows the results of FTIR analysis related to a beta-tricalcium phosphate sample.

FTIR spectra of as-synthesized calcium phosphate powders showed characteristic chemical bands of hydroxyapatite (PO_4 3−, OH−, H_2O absorbed, CO_3 2−, HPO_4 2−) at definite wave number ranges. For example, the band at 1041 cm^{-1} indicates the stretching mode of PO_4 3− in β-TCP (Al-Qahtani et al., 2022).

3.1.2 XRD

Figure 3 shows the XRD analysis of beta-calcium phosphate powder and tablets. As shown in this figure, the pattern of tablet and powder analysis coincides and shows that the nature of the substance does not change by turning it into a tablet.

β-TCP crystallizes in the rhombohedral space group R3c and is usually described in the trigonal setting with unit cell dimensions 10.39 Å for the “a” axis, and 37.43 Å for the “c” axis.

3.1.3 FESEM

FESEM analysis is one of the scanning electron microscope family and is used to examine the surface characteristics and morphology of different samples. In this method, electron beams with specific energy and wavelength sweep the surface of the sample. The main advantage of FESEM analysis compared to SEM analysis is its better resolution due to the field emission electron production source. After converting the powder samples into tablets, FESEM analysis was taken from a number of powder samples and tablets. Gold coating is necessary for FESEM analysis. Figures 4-a and 4-b show images related to the FESEM analysis.

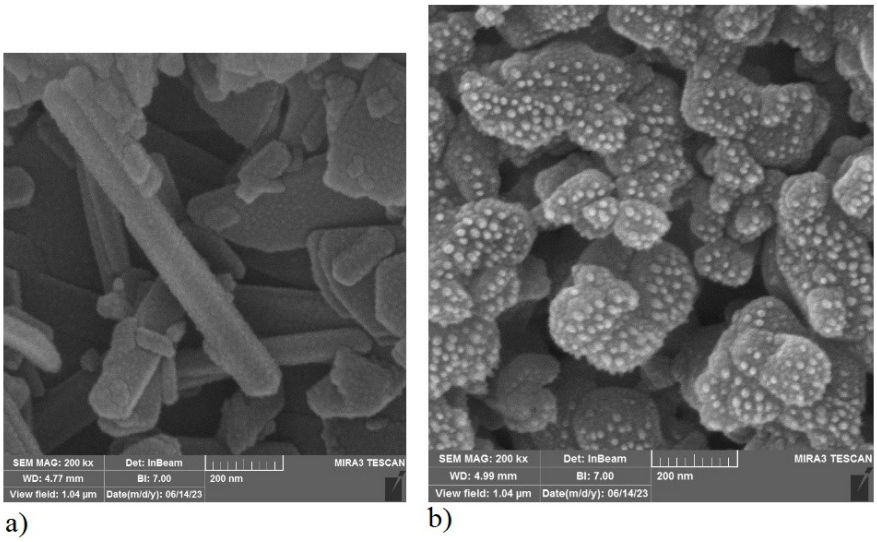
The average grain size of the powder and tablets of this sample is 82.27 nm and 154.56 nm, respectively. As it is known, the grain size increases by turning into tablets.

3.2 Dosimetry results

In the dosimetry study, β-TCP was considered. For this powder and tablets made from them, a table of dosimetry results is provided. In this table, along with the characteristics of the samples, the dosimetric linear range, the linear relationship and, the value of the average temperature of peak formation and the value of the standard deviation of the temperature of the peaks. The tablets produced with this substance, i.e. purchased β-TCP, were made in two separate steps. In the first stage, mandrel and matrix

Table 2: Dosimetric response results of B(M) products.

Sample name B(M)	Linearity Range (Gy)	Linearity Formula (a.u.)	Average Temperature (°C)	STDEVA in Average Temperature (%)
B(M) powder r1	20-1500	$y = 0.0279\,x + 2.6652$	239.87	22.34
1.5 cm without PVA	20-1500	$y = 0.0066\,x + 0.2325$	304.80	33.78
1.5 cm with PVA	20-1500	$y = 0.0075\,x + 0.539$	265.00	21.84
30/2t	20-1500	$y = 0.0166\,x + 0.7964$	183.00	17.94
30/3t	-	-	181.00	-
40/1t	20-800	$y = 0.0539\,x + 0.9177$	180.50	10.37
50/1t	20-800	$y = 0.0623\,x + 0.3766$	184.83	13.01
60/1t	20-800	$y = 0.0377\,x + 2.5811$	183.00	11.26
40/1.5t	20-800	$y = 0.0637\,x + 2.0767$	172.00	11.30
50/1.5t	20-600	$y = 0.0578\,x - 0.3479$	179.00	10.47
60/1.5t	20-600	$y = 0.0612\,x - 0.294$	192.67	16.00
40/1.5t west	-	-	167.00	-
60/1.5t west	-	-	210.50	14.85



a) b)

Figure 4: a) FESEM image of Merck beta tricalcium phosphate powder sample. b) FESEM image of Merck beta tricalcium phosphate tablet sample.

with diameters of 1.5 cm and 4 mm have been used. In the second stage, the tablets were punched using a 6 mm mandrel and matrix. In the production of tablets of the first stage, 2 ml of PVA solution was used per 3.5 g powder. In the production of tablets of the second stage, 1 ml of PVA solution was used per 1 g of powder. As shown in Table 2 and in Fig. 5, most of the samples, including powder and tablets obtained from them, have a linear behavior in the range of dosimetry that were tested. The lowest responses are related to the samples of tablets made with a diameter of 1.5 cm.

As shown in Fig. 5, all the tablet samples made by hydraulic press with diameters of 1.5 cm and 4 mm have less sensitivity than the powder sample, but the tablet samples made with 6 mm diameter have sensitivity more than the powder sample. Therefore, by applying appropriate conditions, it is possible to achieve a better dose response curve in comparison with the powder by turning it into tablets. Figure 6 shows the glow curve of Merck β-TCP samples in different conditions. As shown in Fig. 6, the glow curve of the tablets made with a diameter of 1.5 cm is quite broad and has no sharp peak.

One of the reasons for observing these results can be related to the large surface of the tablet, because it seems that it receives light from more points during reading, and the glow curve produced is the result of the accumulation of a lot of points.

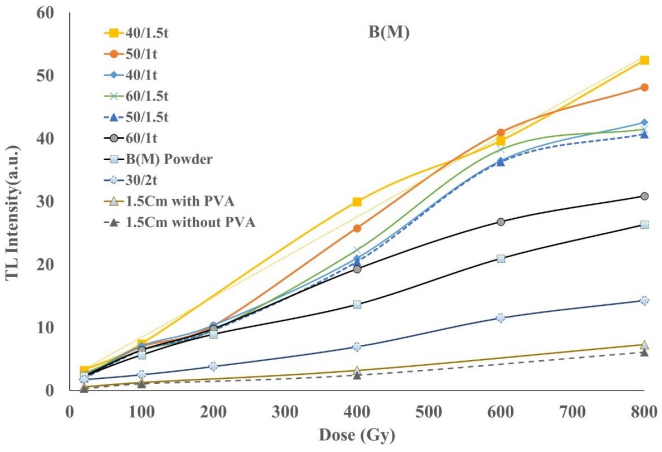


Figure 5: Dose-response curve of B(M) powder samples and tablets obtained from them.

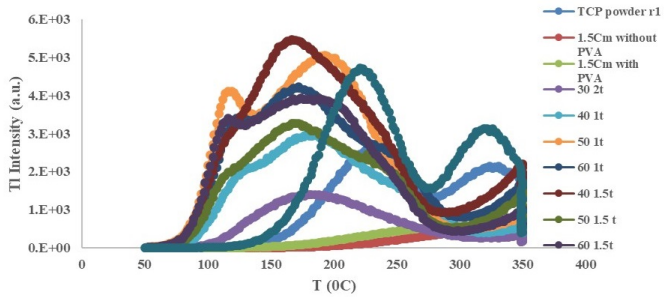


Figure 6: Luminescence curve of B(M) powder samples and their tablets.

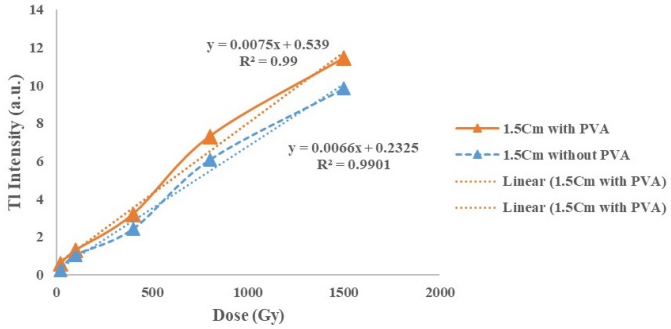


Figure 7: The effect of adding PVA on the sensitivity of B(M) samples.

Another important point regarding these tablets is that, except the sample of tablets produced with a diameter of 1.5 cm, the average temperature of the rest of the tablets produced appears at a lower temperature than the powder and it seems that the applied force has caused the creation of shallower peaks and it must have an effect on the fading curve of the samples as well. As shown in Fig. 6, the behavior of the curves is completely dependent on the conditions and differs from each other. The glow curves related to the sample powder have two peaks. This behavior is also observed in the tablet samples that were pressed with the hydraulic press available in the dosimetry and radiological evaluation laboratory, and the samples have two peaks or have a shoulder at a lower temperature. Although the temperature of the peaks of the tablet has shifted towards a lower temperature, the behavior of the tablets made with a diameter of 4 mm is closer to the tablets made with a 6 mm mandrel and matrix. The observed peak temperature is almost closer to the maximum temperature observed in this set of 6 mm diameter tablets. The glow curve of denser tablets (Tablets with less mass, more force applied) is different from the glow curve of the powder sample, and as can be seen, the samples have a single peak or, finally, at a lower temperature, have a shoulder, and therefore the behavior is different from a powder sample that has two distinct peaks. There is a point in the comparison of two tablets with a diameter of 1.5 cm with PVA and without PVA, the peak temperature of the glow curve of the tablet without PVA is higher and it is formed almost at the end of this curve. The average temperature of the tablet with PVA is 256 °C, also the amount of peak changes is higher for the sample without PVA. According to Table 2 and Fig. 7, the slope of the graph is higher for the sample with PVA and therefore, the sensitivity of the response is also higher.

As shown in Table 2, no specific results are obtained from the comparison of the tablets produced in the second stage with different masses and forces, because the dosimetry results are almost the same. In other words, by changing parameters such as mass and force, no significant relationship can be found in the dosimetric response of tablets. One point that can be obtained from the comparison of the samples made in the second stage is that with the increase in mass and force, the linear range of dosimetry is decreasing. The average temperature value is in the range of 180 to 190 °C, and for these samples, the standard deviation of the peak temperatures is almost the same and is in the range of 10 to 16 and approximately 11. Except for tablets produced with a mandrel and matrix with a diameter of 1.5 cm, the temperature standard deviation of tablets produced from powder is less and therefore the temperature changes of the powder are relatively higher. In making some tablets, the sieving process has not been done. From the comparison of the results extracted from the dosimetric response of unsieved samples and their sieved equivalent, from the comparison of the results extracted from the dosimetric response of unsieved samples and their sieved equivalent according to Table 3, it can be concluded that the unsieved samples have a slightly higher dosimetry response.

Table 3: Comparison of TL dosimetry response of unsieved B(M) tablet samples and their sieved equivalent.

Dose (Gy)	40/1.5t	60/1.5t	40/1.5twest	60/1.5twest
400	29.94	22.32	-	22.79
800	52.41	41.5	59.31	44.67

3.3 Determining the optimal sample

To determine the optimal samples among the tablets produced, the following factors have been taken into consideration:

1. Linear range of dosimetry
2. Sensitivity in the dose-response curve
3. The presence of a single peak in the glow curve
4. Probability of following first-order kinetics (no change in peak position with increasing dose)

These four factors were the basis for selecting the optimal samples and the samples were selected. The samples that had more points in these parameters were selected as optimal samples. After selecting the samples, repeatability tests, fading effects and hardness tests were performed on them.

Table 4: The results of fading, repeatability and microhardness tests for the optimal samples.

No.	Tablet sample	Fading effects percentage for 30 days	Repeatability Percentage	Vickers (HV)
1	1.5 cm without PVA	88.99	23.96	-
2	1.5 cm with PVA	45.57	17.90	16.9
3	30/2t	46.84	10.58	128.6
4	30/3t	-	8.26	-
5	40/1t	42.74	8.88	46.2
6	50/1t	35.31	8.39	50.8
7	60/1t	63.02	9.72	49.7
8	40/1.5t	29.58	23.05	45.5
9	50/1.5t	35.71	11.79	55.5
10	60/1.5t	30.92	9.08	57.3

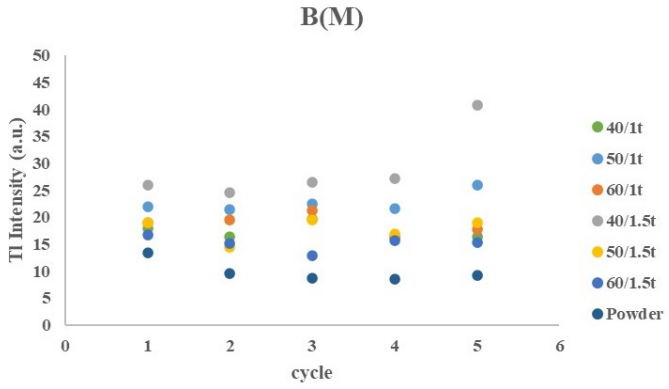


Figure 8: Repeatability diagram of optimal samples B(M).

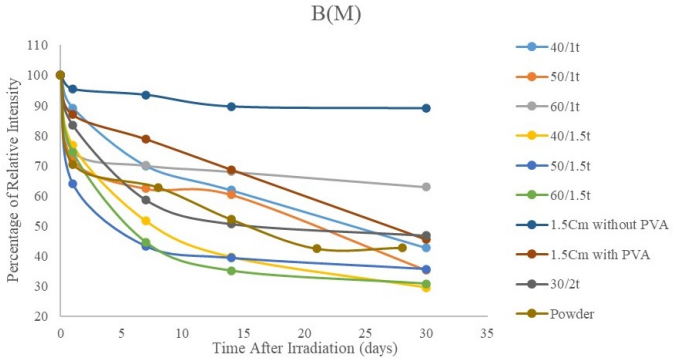


Figure 9: Fading effects of optimal samples B(M).

3.4 Repeatability

As mentioned earlier, the selected optimal samples have been tested for repeatability. This test has been repeated for five periods and for the same tablets at a dose of 400 Gy. The process of zeroing the tablets after each time of irradiation was under the temperature of 400 °C and for 0.5 h. The lowest repeatability percentage for B(M) samples belongs to the 30/3t sample and the weakest sample from this point of view is 1.5 cm without PVA. The repeatability of the powder is approximately 20%. The repeatability diagram of optimal B(M) samples is presented in Fig. 8.

3.5 Fading

In order to perform the fading operation, the response of the samples was examined in a period of 1 month. The time sequence was the day of irradiation, one day after irradiation, one week, two weeks and one month after irradiation. During this period, the samples were kept at room temperature and in a dark place. The only sample that is favorable in terms of fading effects is the 1.5cm sample with PVA, which has almost 90% of its initial response in a period of 30 days. But the rest of the samples of tablets produced from this powder are not in a favorable condition and the weakest tablet from this powder loses nearly 70% of its initial response in fading effects within 30 days. B(M) powder loses more than 60% of its initial response during this interval. Figure 9 the results related to the fading effects of B(M) samples.

3.6 Micro Vickers hardness

The microhardness of the samples was measured using the QB-1000-DAT microhardness tester available in the mechanical properties laboratory of the National Center for R& D of Material Science and Engineering. These tests were performed according to the ISO-6507-1 standard. The Vickers Hardness Number HV is defined as the applied load divided by the indentation surface area and is computed from the equation:

$$HV = 1584.4\left(\frac{P}{d^2}\right) \quad (1)$$

where P is the applied load of up to 1,000 g, and d is the mean diagonal length of the indentation in micrometers (Essabir et al., 2019).

Hardness tests were measured for three points and averaging was done on these three points. In Table 4, you can see the list of optimal samples along with the results of the mentioned tests. From the comparison of the hardness values of the samples according to Table 4 in the microhardness test, it can be concluded that the diameter of the sample can affect the hardness.

In this test, the tablet with a diameter of 1.5 cm has weak hardness. Meanwhile, tablets made with a diameter of 4 mm have the highest degree of hardness, and therefore, it can be concluded that it is better to make tablets with a smaller size in order to reach the optimal conditions of the tablet.

As shown in Table 4, the fading rate of the tablet sample made without PVA is relatively favorable and has approximately 90% of its initial response in a period of 30 days. This is while the tablet sample made with PVA, loses more than 50% of its initial response during this period. However, in terms of mechanical hardness, these tablets do not have favorable conditions and their hardness is very low. The remarkable point about these two tablet samples is that the dose-response curve for these two samples is almost linear in the range of 20 to 1500 Gy and it is better to test for higher doses as well.

4 Conclusions

In this article, commercial β-TCP powder has been prepared and turned into tablets by pressure-less sintering. Then the samples were exposed to Co-60 gamma rays in the dose range of 20 to 1500 Gy.

and then the results were analyzed in terms of thermoluminescence dosimetry. The results of XRD analysis show that the material does not change after turning into tablets. The results of FESEM show that the grain size increases after turning into tablets. The results show that the glow curve of tablets with a large diameter is quite broad and has no sharp peak. One of the reasons for observing these results can be related to the large surface of the tablet, because it seems that it receives light from more points during reading, and the glow curve produced is the result of the accumulation of more points.

One of the important criteria for accepting the sample as a thermoluminescence dosimeter is that the glow curve of the sample follows the first-order kinetics. In the first-order kinetics, the position of the peak does not change with increasing dose, the standard deviation of the temperature changes of the glow curve peaks is lower for the synthesized samples, and therefore, the probability of following the first-order kinetics is higher in these samples.

The standard deviation of the temperature changes of the peaks formed by tablets is lower than that of powder, and therefore, the possibility of first-order kinetics increases when it becomes a tablet.

From the dosimetry results of the tested samples, it can be concluded that unsieved tablets and tablets with a larger diameter of 1.5 cm have a wider dosimetry range and also, by selecting and applying the right conditions for turning into tablets, it is even possible to achieve a higher dosimetric response rather than the powder response. In the micro-hardness test, it can be concluded that the diameter of the sample can affect the hardness. In this test, the tablet with a diameter of 1.5 cm had a weak hardness. In the meantime, tablets made with a diameter of 4 mm have the highest level of hardness, and therefore, it can be concluded that it is better to make tablets with a smaller size in order to reach the optimal conditions of the tablet. In general, based on the scoring of the samples according to different dosimetry parameters such as repeatability, fading effects, sensitivity, the formation of the peaks of the glow curve and microhardness measurement, it can be concluded that the samples with less force have a higher score, and in order to achieve the desired results of converting to TLD dosimetry tablets, it is better to use more mass for tablets if more force is needed. In general, due to the existence of necessary infrastructures for the synthesis and transformation of powder samples into tablets in the country, as well as the appropriate response of these tablets, especially for high doses for use in radiation processing, the existence of economic sanctions in achieving commercial TLD dosimeters, the existence of limitations and obstacles in chemical dosimeters for use in radiation processed products, these optimal combinations of calcium phosphate can be used for industrial dosimetry, especially for radiation processed cases.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work.

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