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Effect of Curing Process on Compressive Properties of Dental Composite Resin

Meshref A. A., Mazen A. A., El-Giushi M. A. and Ali W. Y.

Department of Production Engineering & Design, Faculty of Engineering, Minia University, EGYPT.

***Abstract**: The objectives of this study is to determine the effect of light curing times and curing modes on the compressive properties of hybrid composite resin. The material used was hybrid composite resin of shade A1. The hybrid composite resin specimens were placed in plastic bars with size of 6 mm diameter and 10 mm in height. The specimens were then cured from both sides for 10, 20, 40, 60 and 80 seconds using a visible light curing unit. The light curing modes used were gradually strong, flashing and strong mode. Compression testing was carried out at room temperature on tensometer using spring load 10 KN. Specimens of curing time 40 seconds exhibited higher compressive properties compared to 10, 20, 60 and 80 seconds curing time. The use of gradually strong curing mode resulted in higher compressive properties for the hybrid composites resin compared with the compressive properties obtained using the flashing mode and strong curing mode. This study indicated that, gradually strong curing mode produced dental composite resin with higher compressive properties and 40 seconds curing time gave higher values of compressive properties. Compressive properties results are significantly affected by curing times and curing modes.*

Keywords: Hybrid composite resin, dental composite resin, compressive properties, tensometer, curing modes, and curing times.

1. INTRODUCTION

Dental restoration materials are a sub-group of biomaterials. The two main categories of dental restoration materials are dental amalgam and composite restorative material, [1]. Dental composite resins are tooth-coloured materials that consist of organic resin matrix (dimethacrylate or silorane resins), inorganic fillers (zirconium-dioxide, silicium-dioxide and other glass particles), organo-silane coupling agent, and photo-initiators and accelerators. Composite resins are used as sealants, intracoronal and extracoronal restorations, provisional restorations, veneers, denture teeth, cements, and core buildups. Dental composite resins are formable, can be made to be machineable, opaque or translucent, moderate in stiffness and hardness, thermal and electrical insulators, and sparingly soluble, [2, 3].

Although considerable improvements have been made in the properties of dental composite resins over the years, no composite materials are able to meet both the functional needs of posterior class I and class II restoration and the superior esthetics required for anterior restorations, [4]. Dental restorative materials need to resist the high occlusal forces that occur in the mouth during chewing and to be resistant to ensure steady curative success. These forces can reach up to 200 N in the frontal occlusal area, and up to 800 N in the lateral occlusal segments, or even up to 3500 N during some abnormal jaw movements and teeth contacts. The mechanical properties of dental restorative materials are extremely important for their clinical execution and continuation [2].

So as to improve the mechanical properties such as compressive strength, hardness, and fracture toughness of dental composite resin, earlier studies have concentrated on the evolution of curing techniques and pretreatment of inorganic fillers and resin monomers, [5 - 6]. The mechanical properties of dental composite resin can be affected by various factors; these factors are shown in Fig. 1, [7].

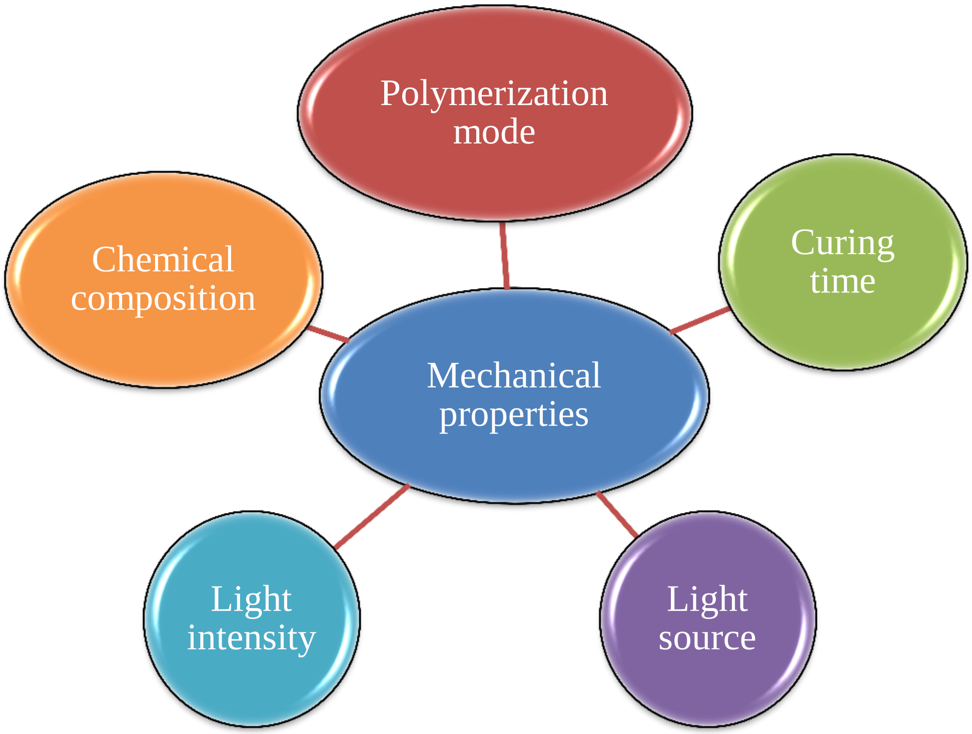

Fig. 1 Factors affected on mechanical properties of dental composite resin. [7]

Most dental composite resins are cured using photoinitiator systems. Although the first light-activated systems used ultraviolet radiation, the light energy source has changed to visible light by the end of the 1970s [8]. The most common light sources used in dentistry to cure dental composite resins are blue light emitting diode (LED), and quartz tungsten halogen [3]. The LED light curing unit is vastly used and displays good results in curing of the dental composite resin. In addition, the LED light source showed a homogeneous curing across the surface of the dental composite resin and good values of Vickers hardness [9].
The mechanical properties of the dental composite resin are related to the quality of curing process. The curing depth of the dental composite resins depends on the curing time, the light intensity and the amount of visible light transmitted through the material, [9]. Curing time depends on several factors, such as light intensity, resin thickness, resin shade, curing through tooth structure, composite filling and box deep, [10]. Various combinations of light intensity and curing time can lead to important differences in the properties of the material within certain energy density. Dentists have an important role in the quality of their restoration by the suitable choice of curing conditions i.e. curing modes and curing times, [11]. Different light curing modes are obtainable such as soft start, step curing, or oscillating irradiation. These special curing modes have been considered to increase the degree of conversion for improving the properties of the material, and to decrease internal stress to obtain better marginal quality in bonded dental composite resin, [12 - 13].

Dental restorative materials and teeth are generally subject to both compressive and flexural forces, so flexural and compressive strength tests are very important to test and determine the mechanical properties of materials, [14]. In the present paper, compression test was used to evaluate the compressive properties of the tested specimens. Compression test gives the mechanical properties that are mainly dependent on the bulk characteristics of a material such as compressive strength, modulus of elasticity, yield strength; modulus of toughness and ductility.

Several studies have examined the influence of light curing modes and curing times on the compressive properties of dental composite resin. Aljosa. et.al, [2] study the effect of curing modes on compressive strength and hardness; they found that the start mode gives higher compressive strength and hardness. On the other hand, Alpöz A., et al., [15] study the effect of the curing times on the compressive strength of dental restorative materials; they found that the compressive strength was improved by increase curing time from 20 to 40 s.

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The aim of the present work is to determine the effect of curing times 20, 40, 60 and 80 seconds and light curing modes (gradually strong, flashing and strong modes) on the compressive properties of hybrid composite resin.

2. EXPERIMENTAL

The material used was a commercially available hybrid composite resin of shade A1. Detailed information about the material used in the present work is shown in Tables 1.

Table 1. Details of Hybrid Composite Resin.

Description	Classification	Manufacturer	Shade	Curing	Lot no.
Visible light cure, Resin-based dental restorative material	Hybrid composite	Prime-Dent, U.S.A.	A1	Light cure	YL08Q

3. PREPARATION OF TEST SPECIMENS

Two experimental groups of hybrid composite resin specimens were prepared; one group to study the effect of curing time, and the other to study the effect of curing mode. Before curing, the specimens were packed into plastic bars 6 mm in diameter and 10 mm in height. The specimens were then curing from both sides using a visible light curing unit (LED) for 10, 20, 40, 60 and 80 seconds. After curing, the specimens were removed from the bars and ground with emery paper (1000 grit size) and then polished. Fig. 2 shows method of preparation of specimens. The dimensions and shape of specimen are shown in Figures 3 and 4, respectively.

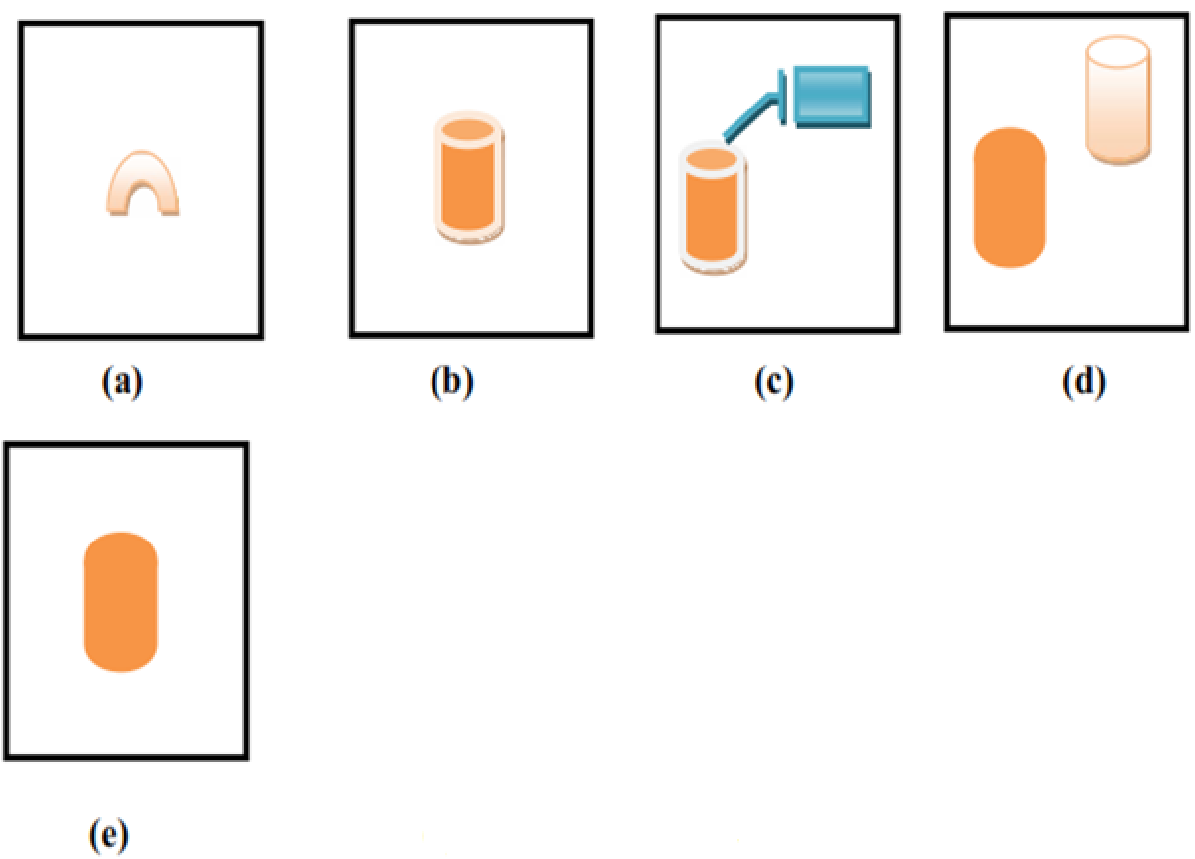

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Fig. 2 Method of preparation of specimen (a) Hybrid composite resin (b) packing (c) curing (d) removing (e) grinding and final shape of specimen.

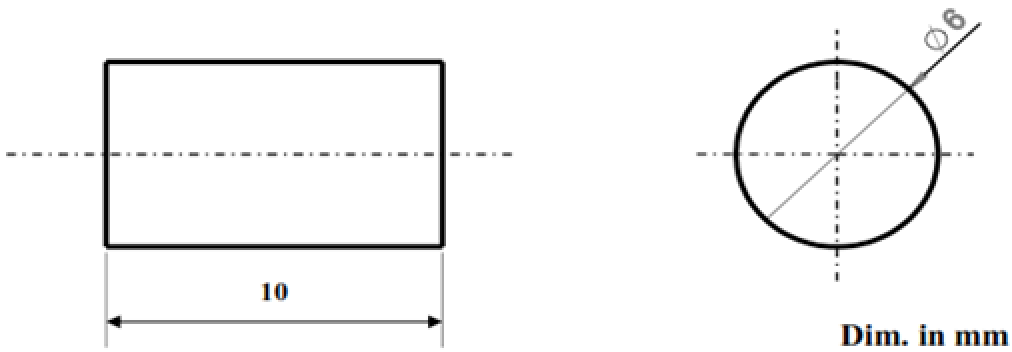

Fig.3 Dimensions of specimen.

Fig. 4 Shape of specimen.

4. CURING OF SPECIMENS

The light source used in this study to cure hybrid composite resin is blue light emitting diode (LED). Figure 5 shows the curing of the specimens by light emitting diode source. Detailed information about the LED is shown in the Table 2. The light curing modes used were as follows; gradually strong, flashing and strong mode. Gradually strong curing mode means emitting of a reduced light energy at the beginning of curing, and increases the energy gradually until it reaches full intensity at the end of curing (Fig.6 (a)). Flashing curing mode means emitting of full light energy and then disappears (Fig. 6 (b)). Strong curing mode means emitting of a constant, stable, full-intensity light-energy (Fig. 6 (c)).

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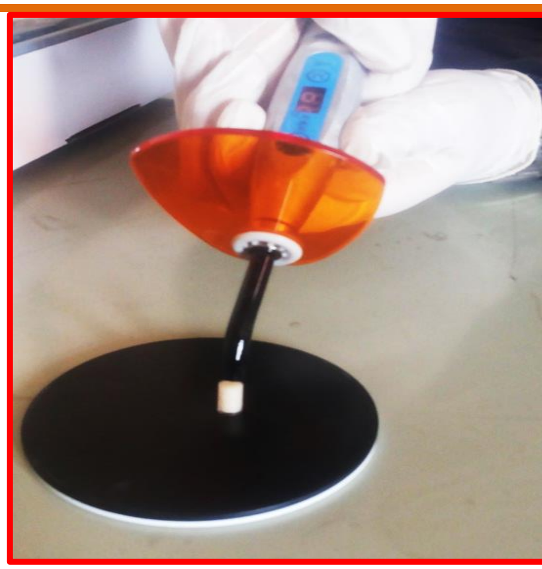
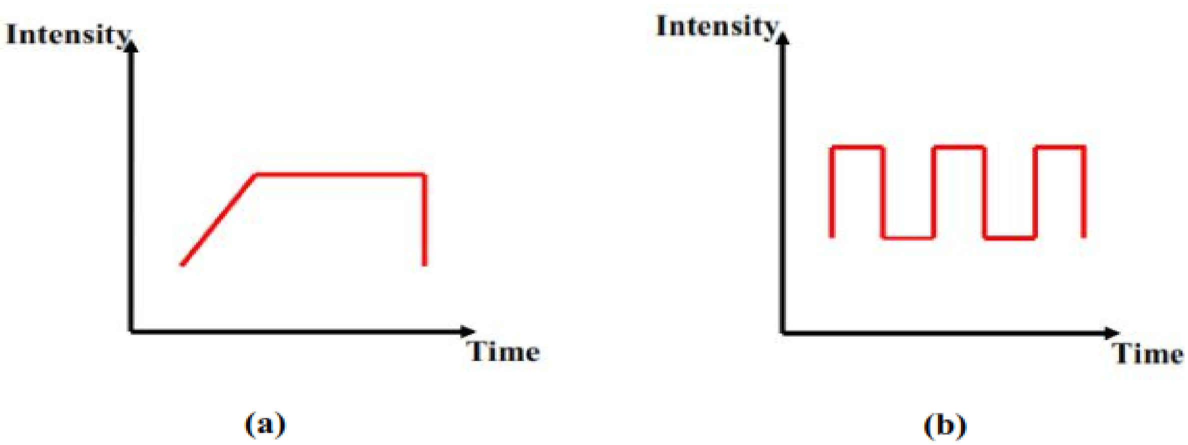


Fig. 5 Curing of the specimens by light emitting diode source.



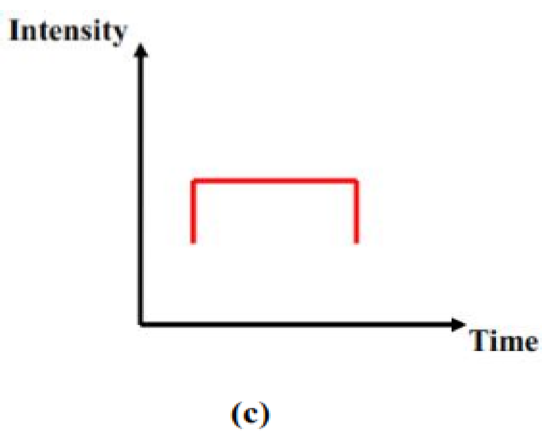


Fig. 6 Light-curing modes (a) gradually strong mode (b) flashing mode (c) strong mode.

Table 2. Details of the Light Emitting Diode (LED)

Intensity (mW/cm^2)	Spectral emission (nm)	Solidify time and depth
1200 - 2000	420 - 480	5s/3 mm

5. Compression Test

Compressive properties of the hybrid composite resin were determined using cylindrical compressive specimens as shown in Fig. 7. Compression testing was carried out at room temperature on tensometer (motor drive unit) using spring load 10 KN. Specimens were placed between the plates of the tensometer as shown in Fig. 7 (b). To decrease the barreling of the specimen surfaces, the friction between the plate of the tensometer and specimen interface was reduced by application of grease. The test was conducted until rupture of specimens. Modulus of elasticity, yield strength (proportional limit), compressive strength, ductility at rupture, and modulus of toughness (U_T) were determined for each specimen using engineering stress- strain diagram.

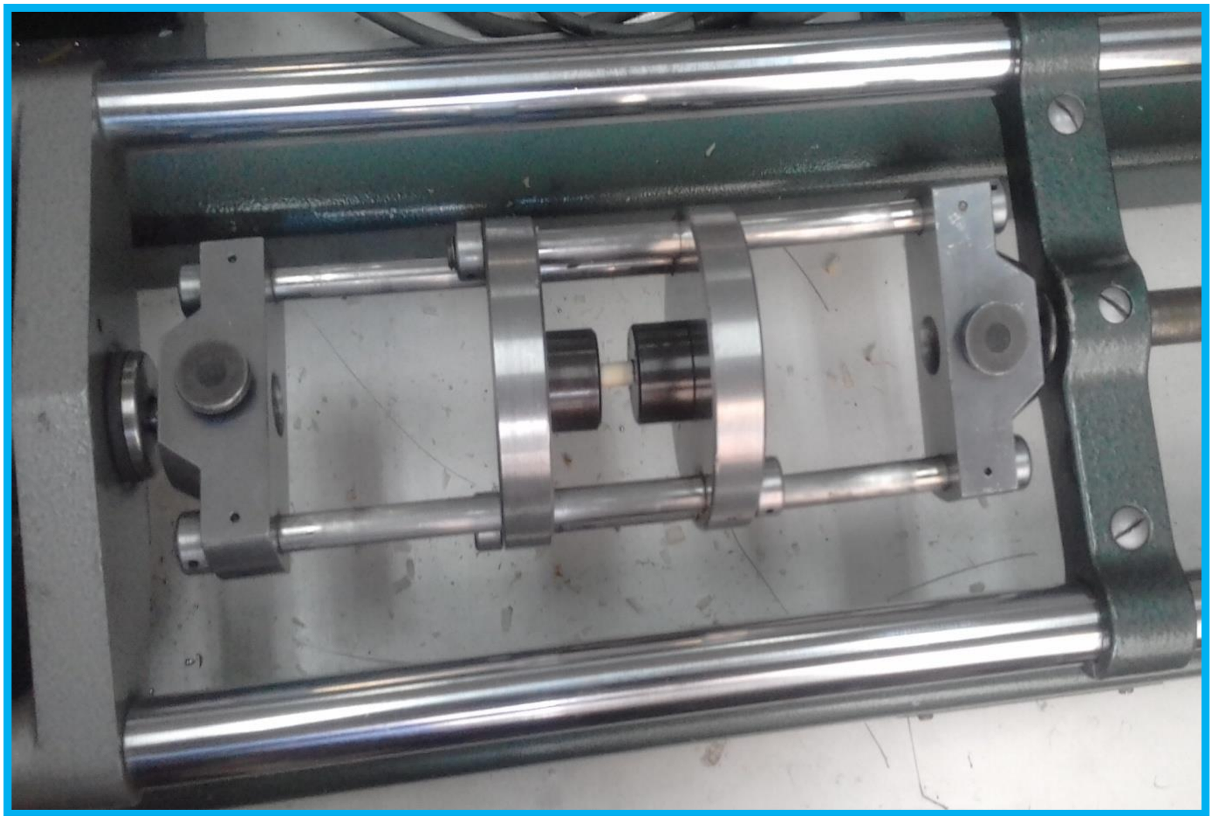


Fig. 7 Compressive test procedure.

6. RESULTS AND DISCUSSION

Results obtained by compression test are shown in Figures 8 – 15. For each curing time and curing mode yield strength (proportional limit), compressive strength, modulus of elasticity, ductility at rupture, and modulus of toughness were determined for each specimen using engineering stress- strain diagram.

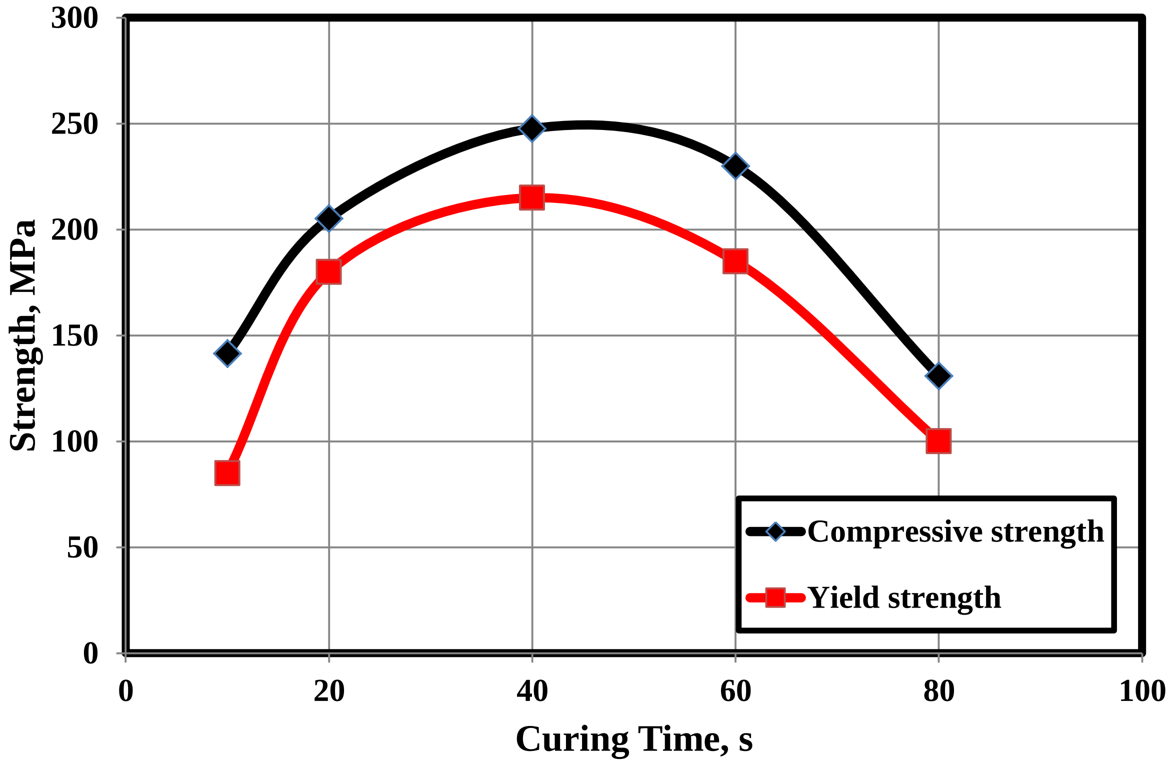


Fig. 8 Effect of curing times on the compressive and yield strengths of the hybrid composites resin cured by strong mode.

The engineering compressive and yield strengths of the hybrid composites resin is plotted as a function of curing time as displayed in Fig. 8. It is clear that compressive strength first increased from 141.5 MPa to 247.7 MPa at curing time of 10 to 40 seconds and then decreased from 247.7 MPa to 130.9 MPa at a curing time of 40 to 80 seconds. This can be explained by the increase of curing time, as curing time increases, degree of conversion increases. The higher the degree of conversion is, the better the mechanical properties (strength and wear resistance) of the hybrid composites resin [16, 17]. The reduction in compressive strength after 40 seconds may be attributed to extra temperature which generated at curing times higher more than it should. Increase the temperature lead to decrease crystalline (less crystalline or branched) which leads to decrease the modulus of elasticity and strength of polymer [18]. The obtained results as shown in Fig. 8 revealed that curing time showed pronounced effects on compressive strength at all used curing times. However, the curing time 40 seconds showed the highest compressive strength ($б_C$ = 247.7 MPa) followed by the curing time 60 seconds ($б_C$ = 230 MPa), then the curing time 20 seconds ($б_C$ = 205.2 MPa), then the curing time 10 seconds ($б_C$ = 141.5 MPa) and lastly the curing time 80 seconds ($б_C$ = 130.9 MPa). The optimal curing time is 40 seconds. In other words, hybrid composites cured at 40 seconds enable to withstand high masticatory (compression) forces in the oral environment.

As it is evident in Fig. 8, the yield strength (proportional limit) first increased from 85 to 215 MPa and then decreased from 215 to 100 MPa with increasing curing time from 10 to 80 seconds. These results are in good agreement with the obtained results of the compressive strength. The reason of increasing the yield strength up to 40 seconds may be attributed to increase the degree of conversion. Over 40 seconds, the extra heat may be led to the reduction of the yield strength. Fig. 8 revealed that the hybrid composites cured at 40 seconds exhibits the highest yield strength followed by the hybrid composites cured at 60 seconds, then the hybrid composites cured at 20 seconds, then the hybrid composites cured at 80 seconds and lastly the hybrid composites cured at 10 seconds. Based on these results, it may be concluded that the hybrid composites resin cured at 40 seconds had higher withstand to deform which led to failure.

The compressive modulus versus different curing times for the hybrid composites resin cured by strong mode is shown in Fig. 9. These data denoted that the apparent modulus of elasticity first increased from 3.54 GPa to 4.54 GPa when curing time increased from 10 to 40 seconds and then decreased from 4.54 GPa to 3.56 GPa when curing time increased from 40 to 80 seconds. This can be explained by the increase in the strength (yield and compressive) up to 40 seconds. Above 40 seconds, the decrease in the strength (yield and compressive) lead to decrease the apparent modulus of elasticity (E= stress/strain, depends on the stress value). As indicated in Fig. 9, the hybrid composite cured at 40 seconds exhibited the highest modulus of elasticity followed by the hybrid composite cured at 60 seconds, then the hybrid composite cured at 20 seconds, then the hybrid composite cured at 80 seconds and lastly the hybrid composite cured at 10 seconds. In other words, the hybrid composite resin cured at 40 seconds is the most stiff as shown by the highest value of the modulus of elasticity. So, the hybrid composite resin cured at 40 seconds had the highest withstand to deform under the masticatory forces (i.e. material with a high compressive modulus will has higher withstand to deform under the masticatory forces).

The influence of curing times on the ductility of hybrid composites resin for strong mode is indicated in Fig. 10. These data denoted that the ductility first increased from 24 % to 68 % when curing time increased from 10 to 40 seconds and then decreased from 68 % 23 % when curing time increased from 40 to 80 seconds. From Fig. 10, it is clear that the hybrid composite cured at 40 seconds exhibited the highest ductility followed by the hybrid composite cured at 60 seconds, then the hybrid composite cured at 20 seconds, then the hybrid composite cured at 10 seconds and lastly the hybrid composite cured at 80 seconds. The hybrid composite cured at 40 seconds and the hybrid composite cured at 60 seconds are significantly better than the hybrid composite cured at 10 seconds and the hybrid composite cured at 80 seconds.

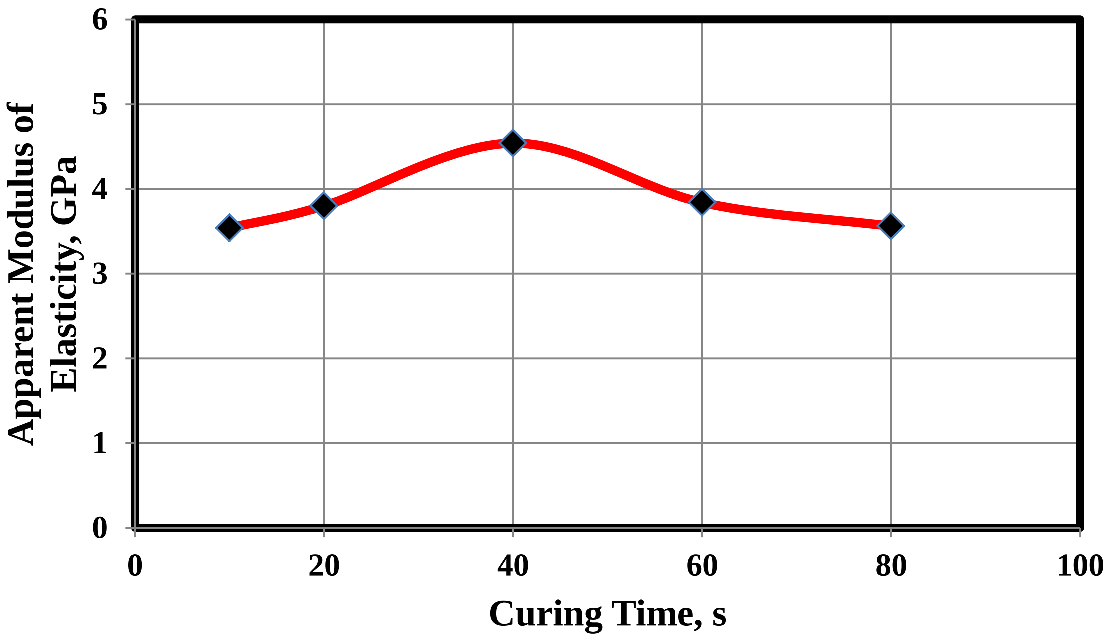


Fig. 9 Effect of curing times on the apparent modulus of elasticity of the hybrid composites resin cured by strong mode.

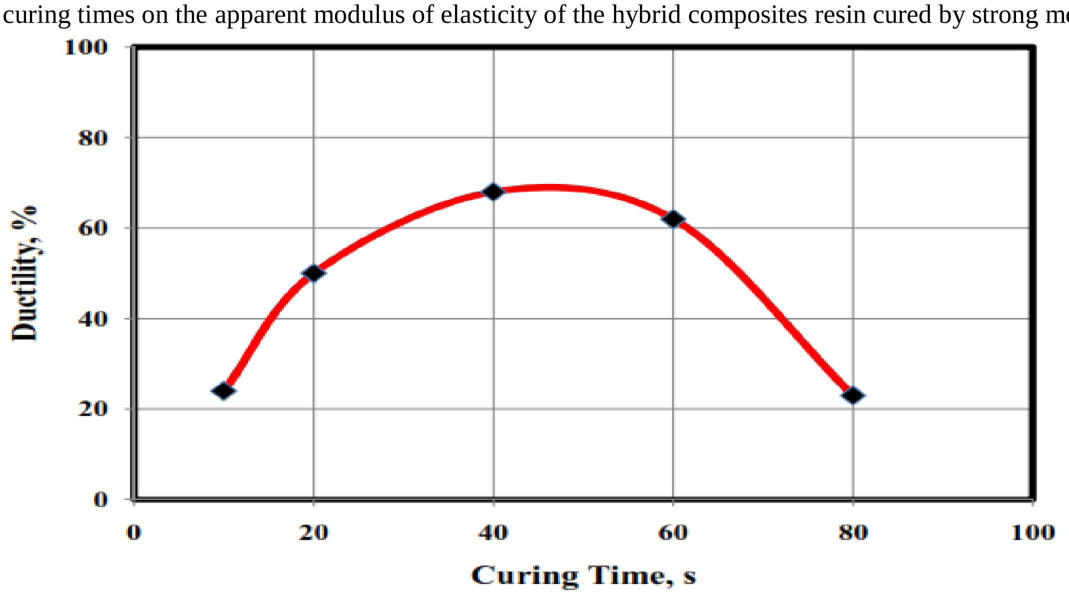


Fig. 10 Effect of curing times on the ductility of the hybrid composites resin cured with strong mode.

The modulus of toughness versus different curing times for the hybrid composites resin cured by strong mode is shown in Fig. 11. As can be seen in Fig. 11, the curing times showed pronounced effects on the modulus of toughness at all used curing times. The modulus of toughness first increased from 27.2 to 157.3 MJ/m^3 at curing time of 10 to 40 seconds and then decreased from 157.3 to 26.6 MJ/m^3 at a curing time of 40 to 80 seconds. This is may be due to the strength and ductility, since modulus of toughness depends on the yield strength, compressive strength and the strain at rupture. The highest modulus of toughness is produced by the hybrid composite cured at 40 seconds, followed by the hybrid composite cured at 60 seconds, then the hybrid composite cured at 20 seconds, then the hybrid composite cured at 10 seconds and lastly the hybrid composite cured at 80 seconds. This means that the hybrid composite cured at 40 seconds is tougher than the hybrid composite cured at 60, 20, 10 and 80 seconds.

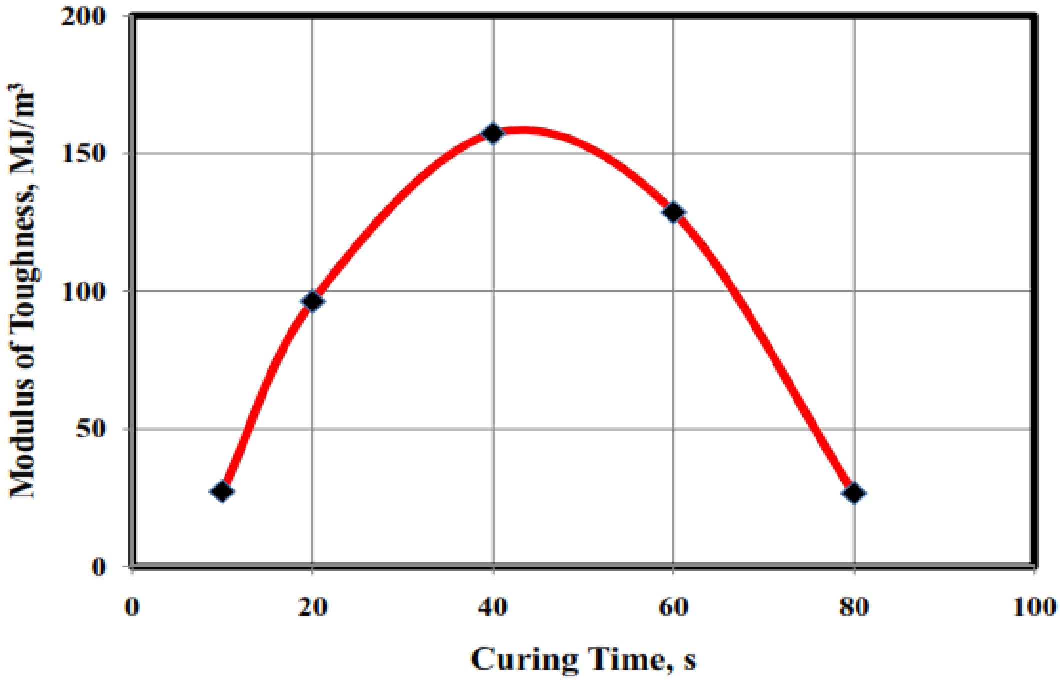


Fig. 11 Effect of curing times on the modulus of toughness of the hybrid composites resin cured by strong mode.

Figure 12 shows the variation of the compressive and yield strengths against the methods of curing used in this study. The obtained results as presented in Fig. 12 revealed that curing modes showed pronounced effects on the compressive strength at all used curing modes. From Fig. 12, it is clear that the hybrid composite resin cured with gradually strong mode had the highest value of compressive strength ($б_C$ = 177 MPa) , followed by the hybrid composite resin cured by flashing mode ($б_C$ = 152.2 MPa), whereas the hybrid composite resin cured with strong mode showed minimum compressive strength ($б_C$ = 130.9 MPa). This can be explained by the change in the temperature which generated during the curing process by different curing modes. The temperature generated by gradually strong mode is less than this generated by strong mode. Different curing modes lead to different polymer structures [19]. Flinn R. etal. [18] reported that when the temperature increase, the crystalline decrease and that lead to reduce of the modulus of elasticity and strength of polymer. Thus, the hybrid composite resin cured by gradually strong mode is stronger than the hybrid composite resin cured with strong mode.

The influence of curing modes on the yield strength (proportional limit) of hybrid composite resin cured is indicated in Fig. 12. These data denoted that the hybrid composite cured by gradually strong mode exhibited the highest yield strength followed by the hybrid composite cured with flashing mode and lastly the hybrid composite cured by strong mode. These observations could be related to the change in the temperature which led to the change in the structure of hybrid composite resin. Based on these results, it may be concluded that the hybrid composite resin cured by gradually strong mode has higher withstand to deform which led to failure. Whereas, the hybrid composite resin cured with strong mode has the lower withstand to deform.

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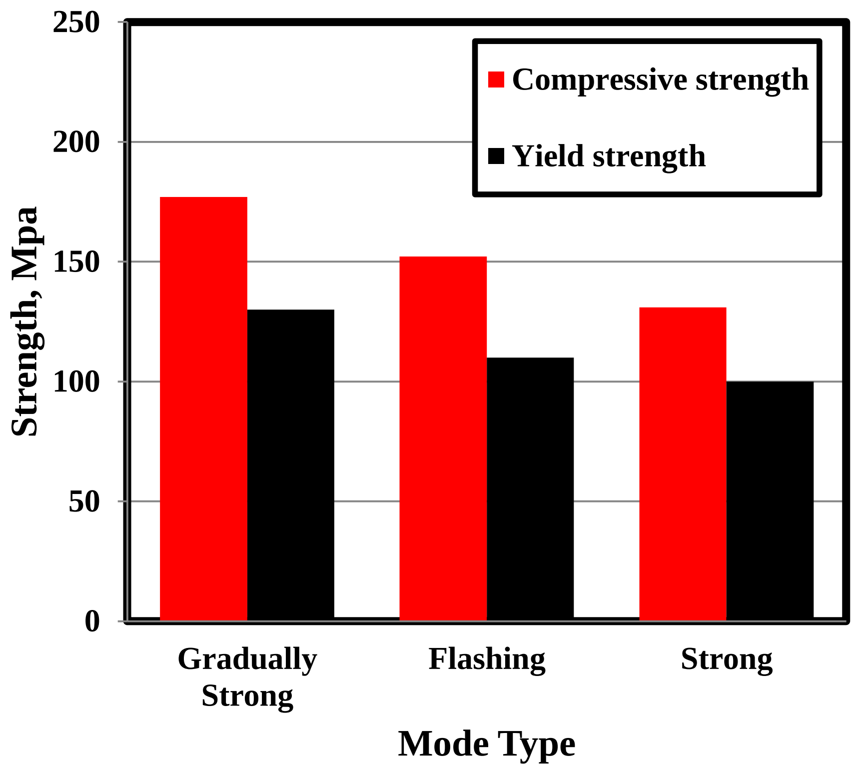

Fig. 12 Effect of curing modes on the compressive, yield and rupture strengths of the hybrid composite resin cured at 80 seconds in case of as received.

The compressive modulus versus different curing times for the hybrid composite resin cured at 80 seconds is presented in Fig. 13. As can be seen in Fig. 13, the highest apparent modulus of elasticity was obtained in the hybrid composite resin cured with gradually strong mode, then the hybrid composite resin cured by flashing mode and lastly the hybrid composite resin cured with strong mode. This is because the strength (yield and compressive) as discuss above. This means that the hybrid composite resin cured with gradually strong mode is the most stiff as shown by the highest value of the apparent modulus of elasticity. So, the hybrid composite resin cured with gradually strong mode had the highest withstand to deform under the masticatory force. These results suggest that in order to optimize the stiffness of dental hybrid composite resin, it is important to cure dental hybrid composite resin by gradually strong mode.

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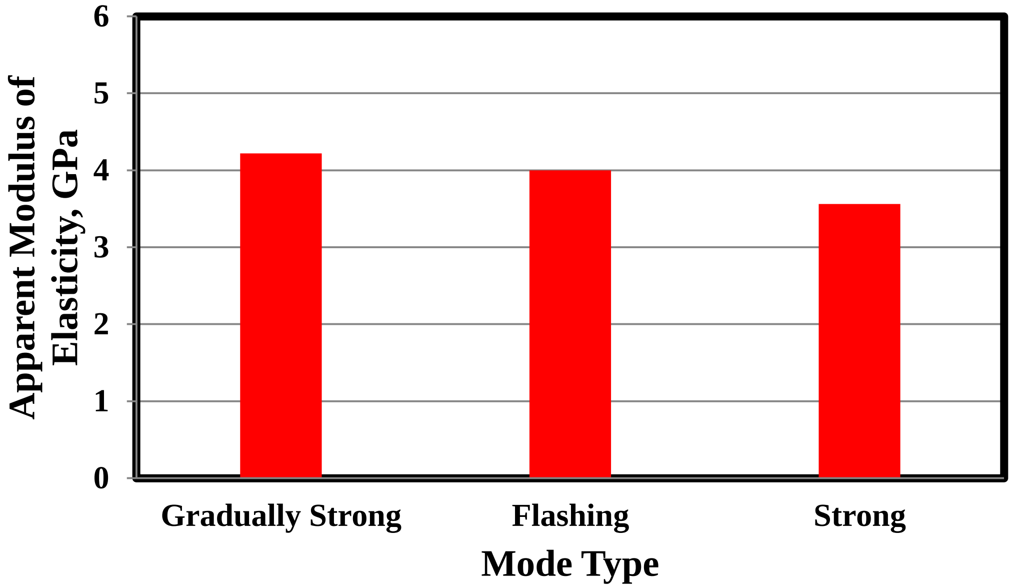

Fig. 13 Effect of curing modes on the apparent modulus of elasticity of the hybrid composite resin cured at 80.

The ductility of the hybrid composite resin is plotted as a function of curing modes for curing time 80 seconds as displayed in Fig. 14. The obtained results revealed that the hybrid composite resin cured by gradually strong mode more ductile than the hybrid composite resin cured with flashing mode and the hybrid composite resin cured by strong mode. The hybrid composite resin cured by flashing mode had less ductility than the hybrid composite resin cured by gradually strong mode and was thus more brittle.

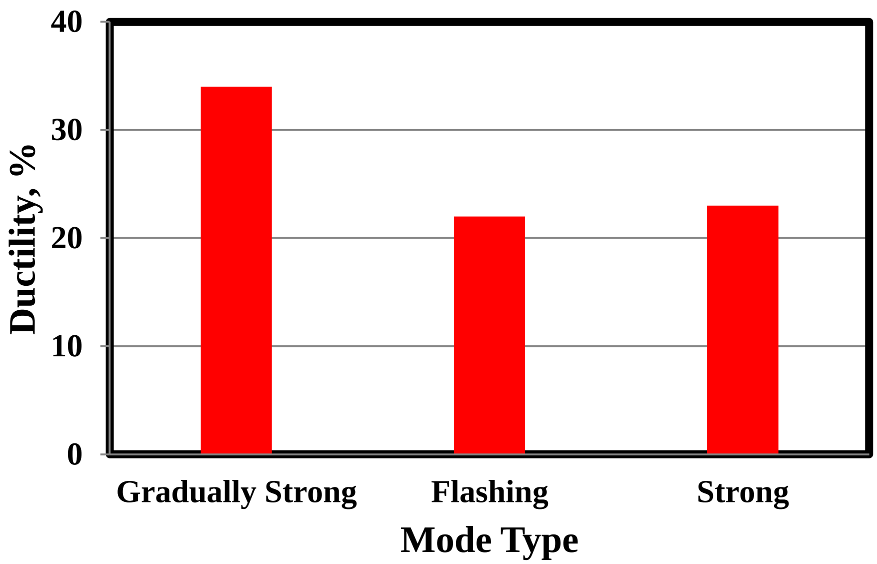

Fig. 14 Effect of curing modes on the ductility of the hybrid composite resin cured at 80 seconds in case of as received.

Figure 15 appears the relationship between the modulus of toughness and the curing modes for the hybrid composite resin cured at 80 seconds. As indicated in Fig. 15, the high modulus of toughness was produced by the hybrid composite resin cured by gradually strong mode, followed by the hybrid composite resin cured with flashing mode and lastly the hybrid composite resin cured by strong mode. The decrease in the strength and the strain at rupture may be responsible for the falling in the modulus of toughness. Fig. 15 revealed that the hybrid composite resin cured by gradually strong mode was tougher than the hybrid composite cured with flashing mode and the hybrid composite cured by strong mode.

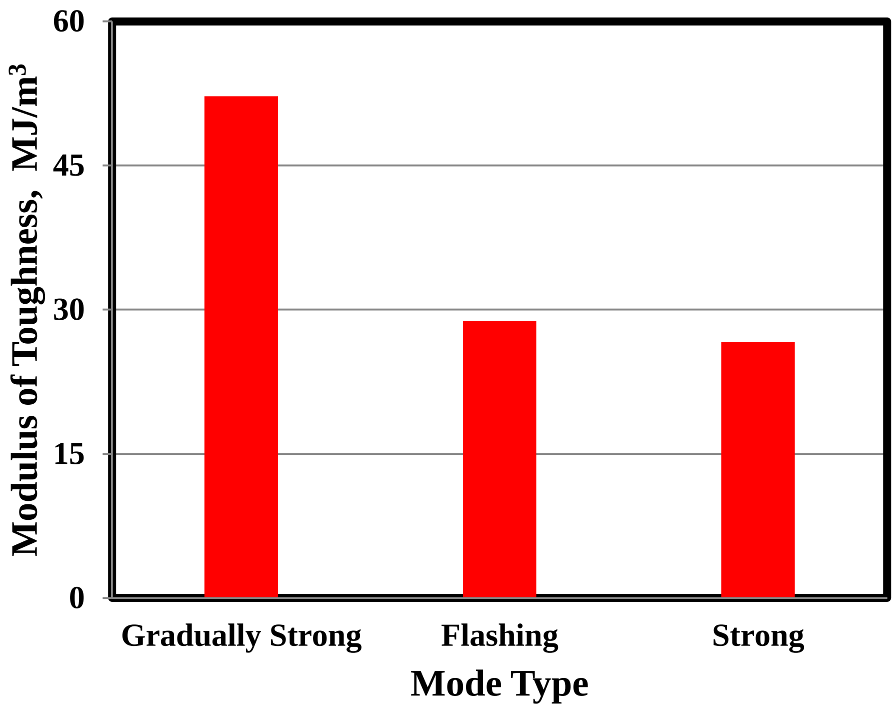

Fig. 15 Effect of curing modes on the modulus of toughness of the hybrid composite resin cured at 80 seconds.

7. CONCLUSIONS

Based on these results, it may be concluded that compressive properties results of hybrid composite resin are significantly affected by curing times and curing modes. Curing time 40 seconds gives hybrid composite resin with higher compressive properties such as compressive and yield strengths, modulus of elasticity, modulus of toughness and ductility. Gradually curing strong mode produces dental composites resin with excellent compressive properties such as high strength, high stiffness, high toughness and high ductility. Dentists can use 40 seconds curing time and gradually curing strong mode using the light emitting diode (LED) source for curing the tested materials used in this study.

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