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Effect of Notching on Impact Strength of Thermocyclyed Acrylic Resin Denture Base Material

[1]Mohamed M. Shehata, [2]Magdy M.M. Mostafa and [3]Amal H. Moubarak

[1]Professor, Dental Biomaterials Division, Conservative Dentistry Dept., Faculty of Dentistry,King Abdulaziz University, Jeddah, Saudi Arabia.
[2]Professor, Removable Prosthodontics. Division, Oral and Maxillofacial Prosthodontic Dept., Faculty of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia and Prosthodontics Dep. Faculty of Dentistry. Tanta University, Egypt.
[3]Professor, Removable Prosth. Division, Oral and Maxillofacial Prosthodontic Dept., Faculty of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia and Prosthodontic Dept. Faculty of Dentistry. AinShams University, Egypt

ABSTRACT

This research study was performed to explore the behavior of acrylic resin denture base material during impact loading with molded versus machined notching under different temperatures. Two forms of notching (molded and machined) were done equally in all specimens. Then, each group was subdivided into eight subgroups according to the subjected degree of temperatures. The selected temperatures (0, 10, 18, 28, 45, 55 and 70°c) were chosen to cover a wide range similar to actual service temperatures. All specimens were soaked in distilled water at the designated temperatures. One hour and two hours were chosen as the time for soaking and the results of both were recorded. The results revealed a slight increase of fracture energy was developed with initial increase of temperature then followed by a decrease in fracture energy with further increase of temperature. An explanation of fracture energy increase is due to the increase of internal frictional resistance of polymer chains movement due to the impact load. This movement becomes easier at higher temperatures, which contribute to a decrease in fracture energy with further increase in temperatures also, the same tests were repeated with specimens with formed notches. These specimens showed a higher increase' in fracture energy compared with the cut notch specimens.

Key words: Acrylic resin material, Temperature effects, Impact strength, Izod impact test and storage time.

Introduction

Polymethyl methacrylate (PMMA) based polymers are the materials most commonly used for the construction of removable dentures due to their working characteristics, ease of manipulation, clinical serviceability and satisfactory aesthetics (Durkan, *et al.,* 2010; Jagger, *et al.,* 2003).

In the oral cavity, the denture prostheses are usually under conditions of thermal variations due to the ingestion of hot and cold liquids (Barclay, *et al.,* 2005; Ernst, *et al.,* 2004; Palmer, *et al.,* 1992). Such thermal cycling in a wet environment may cause degradation of the denture polymers (Kawano *et al.,* 2000; Hargreaves,1983). Heating the acrylic resins may enhance further polymerization reactions, consequently, an improvement in the mechanical properties can be expected. Hence, the possible effect of thermal cycling on the mechanical properties of the acrylic resins must be considered (Urban, *et al.,* 2009).

A frequent problem that occurs with removable dentures is fracture, which may be due to accidental dropping, repeated masticatory forces, and areas of stress concentrations around frenal notches (Barclay *et al.,* 2005). Impact test is often used to evaluate the denture base materials since it represents one important aspect of real life service of such material. Impact testing of acrylic resin material was accordingly a subject of study by many researchers in the field of dental materials (Ernst, *et al.,* 2004 ; Palmer *et al.,* 1992) .

Brooks and Huggett, (1986) reviewed a remarkably large number of behavior of plastics. Specimens had been thrown, dropped and subjected to blows from hammers, falling weights, and pendulums. Comparisons of results of such diverse testing procedures are of little value. However the most common types of impact tests are those utilizing the swinging pendulum, either Charpy-Notch test or lzod test

The problem of impact testing is that inconsistent results can be obtained, because specimens break at different conditions. In order to ensure more consistent results, specimens are notched. The material fracture at the notch, since it is its weakest part. A notch also makes the material more brittle; hence, this is a severe test of toughness of a material. Robinson and McCabe, (1993) reported that the impact resistance of acrylic resins was

Corresponding Author: Amal H. Moubarak, Removable Prosth. Division, Oral and Maxillofacial Prosthodontic Dept., Faculty of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia and Prosthodontic Dept. Faculty of Dentistry. Ain Shams University, Egypt
E-mail: amalscientific@yahoo.com

significantly reduced by the presence of very small surface defects (< 1 Gum) and this was particularly noticeable for the so-called high-impact resins (Robinson and McCabe, 1993).

All polymer specimens were notch sensitive regarding impact energy (Brooks and Huggett,1986). Addition of cross-linking agents with high percentage decreased the mechanical properties of acrylic resin material regarding tensile strength and impact strength (Arima *et al.,* 1996).

When polymethyl-methacrylate containing the ultra-high modules polyethylene fibers breaks, the whole system coheres without fragments breaking (Braden, *et al,* 1988). The effect of including 0.5-4 % weight of 6mm length of ultra-high modules polyethylene fibers on the impact strength of acrylic denture base resin. It was concluded that the inclusion of small proportion of fiber in the resin (1%) produced impact strength greater than those exhibited by the more expensive, commercial, high impact materials (Gutteridge, 1988).

The addition of 20% volume and 40% volume hollow micro-sphere filler significantly reduced impact strength of the denture base resin, they added this filler to decrease the weight of the prosthesis which may increase the retention of selected maxillary prosthesis (Yen *et al.,* 1991). The impact strength of specimens containing 1 or 2 percent by weight of plasma treated ultra-high modules polyethylene fiber was not significantly different from that of untreated fiber specimens (Gutteridge, 1988).

The effect of reinforcing denture polymethyl-methacrylate with glass fibers on the impact strength they concluded that both types of reinforcement increase the impact strength of the test specimens. And there was no clear difference between the mean impact strength value of the test specimens reinforced with metal wire and that of the specimens reinforced with glass fiber (Vallittu, *et al.,* 1995).

The mechanical properties of denture base polymer reinforced with five layers of polyethylene woven fiber. They concluded that reinforced polymethyl-methacrylate with woven fiber showed improvements in flexural stiffness and impact strength as well as reduction in water sorption, polymerization shrinkage and dimensional changes during water immersion. Incorporation of woven fiber into the resin also produced a notch-insensitive material (Clheng, *et al.,* 1997).

The impact, toughness and resilience characteristics of acrylic denture base resins decreased with an increase in temperature from 23°C to 60°C. And there was an adequate correlation between the impact characteristics and the amount of the residual monomer also he concluded that at relatively low impact hitting speeds seen in chewing, the impact characteristics of denture base resins was very susceptible to temperature and/or residual monomer. It is worth mentioning that he did not use standard Izod tesing device during his investigation (Oku, 1989).

In this study, the effect of molded versus machined notching on the impact properties of the thermo-cycled Acrylic resin material under broad range of temperatures was investigated.

Materials and methods

Specimens Specifications

Three hundred sixty specimens were processed according to British Standard Institute Specification no 771. Each specimen had the dimensions of 75 mm (length) X 10 mm (width) X 10 mm (thickness) with a standard notch of 2 mm (depth) at the mid-span.

Specimens preparation

Mold preparation

The specimens were produced in molds made by investing aluminum pattern blocks of the required size into gypsum. The stone mix was prepared according to the manufacturer's instructions and vibrated to expel out air from it then it was poured into the lower half of the flask. The aluminum metal block was embedded in the investing medium until the surface of the block became as nearly horizontal with the flask edges as possible. The excess stone was removed with spatula. After setting of stone, its surface was smoothened and coated with a thin layer of sodium alginate to prevent the stone that is poured in the upper half of the flask from adhering to that in the lower half. The upper half of the flask was placed in its position and another stone mix was poured in it then the flask was covered with its lid and left for two and half hours for complete setting. The sections of the flask were separated and the aluminum block was carefully removed leaving the mold space, then the mold space was washed by running hot water to remove any stone debris in the mold and was left to dry for five minutes to avoid the presence of excess water before being painted with sodium alginate. Because the resin should be carefully protected from the gypsum surface surrounding the mold space, so sodium alginate separating medium was applied to the mold space providing a thin and uniform coating.

Packing and curing of the acrylic resin:

Heat cured PMMA was used for fabricating the test specimens. The proper monomer to polymer ratio as recommended by manufacturer was used (2.34 gm powder to 1 ml liquid), and was thoroughly mixed and allowed to reach the dough stage in air-tight mixing Jar, then it was packed into the mold space.

Two sheets of cellophane papers were used to cover the acrylic dough to prevent its adhesion to the lower mold surface during the trial closure. The cellophane papers were removed and the two halves were closed under pressure which was maintained until the specimens have been processed.

All sets of specimens were subjected to the same curing cycle. The flask was submersed in tap water then the temperature of the water bath was raised to 72+1°C and maintained for one hour followed by one hour boiling to ensure high degree of polymerization. The mold was then allowed to bench-cool to room temperature before deflasking.

Storage

The specimens were stored in distilled water at room temperature for 48 hours followed by one or two hours storage at the testing temperature before testing. Accordingly, specimens were divided into two equal groups (180 specimens each) after one hour and two hours of soaking. Then, each group was subdivided equally into 8 subgroup corresponding to different degrees of temperatures starting from 0° till 70° with increase by 10 degrees ascendingly.

Notching

Each subgroup was subdivided equally into two categories (molded and machined notch). Notched specimens (Fig 1) were smoothed with successively finer grades of wet silicon carbide papers. The specimens were not polished, since polishing with pumice slurry causes rounding of the edge of the notch and therefore reduce its effective depth.

The same procedure previously described for processing acrylic specimens was carried out for the cut notch specimens except that the notch has been made after processing the specimen using milling machine with appropriate cutting tool. A milling cutter with an angle of45° was used to make the notch in all specimens.

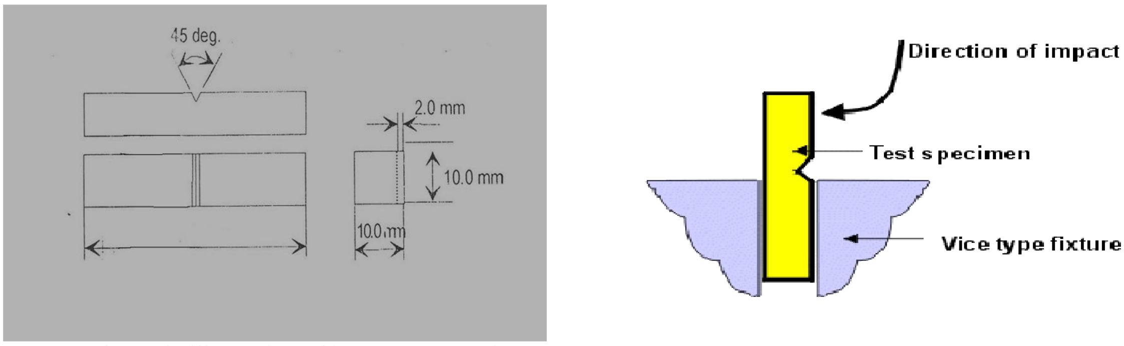

Fig. 1: Schematic illustration of impact test specimen

Impact Strength Testing

A typical Izod impact test was used to deliver a blow to the specimen and to measure and record the amount of impact energy consumed in fracture each specimen. The test specimen was held vertically in the vice of the testing machine. It was fractured with the help of a falling hammer.

The energy (E) required for breaking the test specimens were calculated using the following formula
$(E = WE(\mathrm{Cos}\beta - \cos\alpha) - L)$.Where,
E: energy required for breaking the test specimen, in Joule.
W: Weight of pendulum, in Newton.
R: Distance from axis of rotation to the center of gravity of pendulum, in meter.
α: angle of fall of pendulum.
β: angle of rise of pendulum after breaking the specimen.
L: Loss of energy due to friction, in Joule

Results

Effect of soaking time:

The results of all Izod impact tests which were performed on acrylic resin specimens showed that, the scatter associated with the results of specimens soaked in distilled water for two hours was less than the scatter of one hour soaked specimens all over the range of temperature (fig.2&3). Also, the figures demonstrated that, the impact energy required to fracture the material slightly increased with temperature increase.

Effect of notching:

The results presented in fig.4 demonstrated that, the machined notch specimens required lower energy to fracture when compared with molded notch specimens

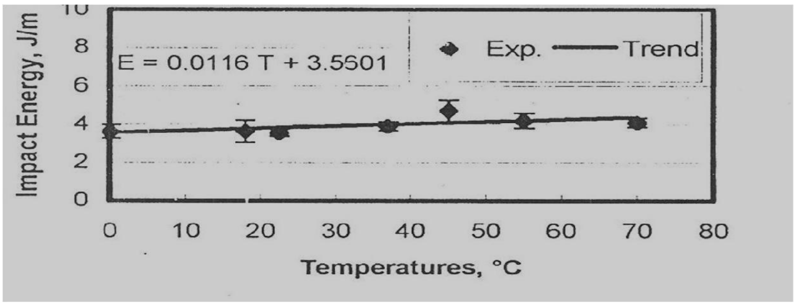

Fig. 2: Impact energy of DMMA at different temperatures for two hours soaked specimens

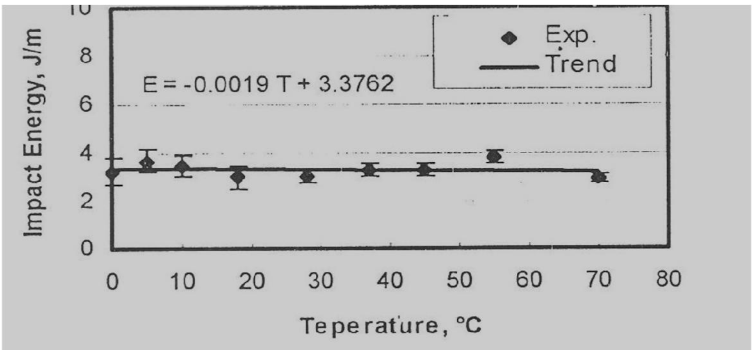

Fig. 3: Impact energy of DMMA at different temperatures for one hour soaked specimens

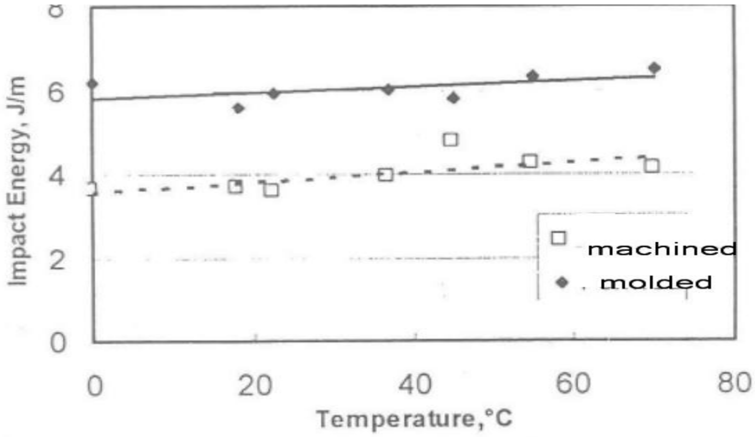

Fig.4: Impact energy of DMMA at different temperatures for molded versus machined notch specimens

Discussion

The Izod type test selected for the present study have been used by investigators to evaluate the mechanical properties of denture base acrylic resins.

Over time, denture base resins are routinely exposed to a wide range of temperatures in a wet environment (Barclay, *et al.,* 2005; Ernst, *et al.,* 2004; Palmer, *et al.,* 1992), and therefore it is important to establish whether these changing oral temperatures affect their mechanical properties. Thus, it has been suggested that thermal cycling should be part of the testing protocol for dental polymers. Thermal cycling is an in vitro process where test materials are subjected to temperature extremes using water baths in an attempt to simulate conditions in the oral cavity.

Mimicking one of the *in vivo* degradation factors involved (such as the thermal stresses which denture polymers will be exposed to in the oral cavity) is useful to disclose its effect on the general degradation process. Thus, in vitro study, the materials were subjected only to thermal cycling. Based on these findings, it is possible that variations in oral temperature will have an overall positive effect on denture bases fracture. However, it should be noted that clinical conditions differ from the in vitro setting; for this reason, these findings must be carefully interpreted.

The formed notch specimens as shown in fig.4 consumed remarkably more energy to fracture when compared with machined notched specimens. This can be attributed to higher concentration factors that occur at sharper notch bases. Hence at sharper notch base, cracks start faster when compared with molded notches, Accordingly this indicate that any cuts in the material may lead to a failure sooner when compared to molded notch like shapes. This is in agreement with Eraser and Ward, (1974) as they concluded that the impact testing using a blunt notch, for example a notch with 45° included angle, causes difficulty in forming the initial craze and the resulting crack on the surface of the specimen. However for sharp notch, the conditions for craze and crack initiation exist.

It is clearly observed that the data of molded notch was pertaining higher scatter compared with data of machined specimens. This is attributed to the notch radius formed during frenal notches of denture on the impact strength. As the labial frenal notch has been stated to be an important factor contributing to midline fracture (Obeid, *et al.,* 1982).

In both cases molded and machined notches, fracture energy was shown to increase slightly with the increase of testing temperature, especially at temperature above 45 °C. General trend lines were added to (Fig. 4), the trend lines show that there is an increase in the fracture energy due to increase in temperature. Even though this trend was slight, but it existed in both cases, molded as well as machined notch specimens. This slight increase of fracture energy at higher temperatures can he attributed to the energy spent on moving linked polymer chains before fracture. Since increase of temperature increases the intermolecular distances, which in turn allows more freedom for polymer chains to make relative movements prior to failure. This form of relative motion or viscous flow consumes more energy when the hammer of the impact device strikes the specimens.

It is to be noted that this increase of fracture energy due to temperature increase is not monotonic. As the temperature increase, intermolecular distances increase the resistance to fracture decrease in the presence of week van-der-waal forces. This accounts for decrease in fracture energy with further increase of temperature. Oku, (1989) concluded that the impact strength decrease with temperature increase from 25°c-60 °c. The author followed different technique in measuring the impact strength and he did not report how he determined the time of fracture of specimens (Silva, *et al.,* 2013).

Conclusions

From the previously presented study, it is concluded that

- The scatter associated with the results of specimens soaked in distilled water for two hours was less than that soaked for one hour.
- The impact energy required to fracture the material is increased slightly with temperature increase. This slight increase of impact energy at higher temperatures was not monotonic.
- Machined notch specimens required lower energy to fracture when compared with molded notch specimens

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