Determining the Dimensional Stability, Fracture Toughness and Flexural Strength of Light-cured Acrylic Resin Custom Tray Material

S. B Khan* and G. Geerts[†]

Abstract - *Light-cured acrylic resin custom tray material is used in commercial dental laboratories but little evidence-based scientific information on its physical properties is available.* **Objectives:** *This study investigates the dimensional stability of light-cured acrylic resin custom tray material and compares its fracture toughness and flexural strength to a chemically-cured acrylic material.* **Method:** *For dimensional stability, 20 light-cured specimens were fabricated and measured 3 times at regular time intervals over 48 hours. Mean shrinkage was calculated for each time interval and the mean values were compared to the standard using the Wilcoxon Rank Sum test. A p-value of <0.05 was considered significant. For fracture toughness, 2 groups of 20 light-cured and chemically-cured acrylic materials with a single-edge notch were subjected to a compressive load using the 3-point bending technique. For flexural strength, 1 group (n=20) of each material was subjected to a compressive load using 3-point bending. The highest load before failure was used to calculate the fracture toughness and flexural strength. Differences in fracture toughness and flexural strength values between the 2 groups were compared using ANOVA testing. A p-value of <0.05 was considered significant. The chemically-cured group was accepted as the control group.* **Results:** *Compared to the standard, shrinkage was significant for all time intervals (p<0.05). The difference in shrinkage among time intervals was not significant (p>0.05). The fracture toughness and flexural strength were significantly higher for the light-cured material.* **Conclusions:** *Trays made from light-cured acrylic resin can be used immediately following polymerization. The light-cured material is more resistant to bending and crack propagation than the chemically-cured type.*

KEY WORDS: Custom tray; polymethyl methacrylate resin; chemically-cured; light-cured; dimensional stability; fracture toughness; flexural strength.

INTRODUCTION

The importance of using custom trays in producing accurate casts has been emphasized in a number of publications.[1-10] Polymethyl methacrylate (PMMA) resins are popular materials for making custom trays. Chemically-cured (CC) PMMA resin has been researched extensively and has a clinically proven record.[11-16] Light-cured (LC) resin has been introduced as an alternative to the CC material. New materials should improve on the physical properties, biocompatibility and ease of use.[11]

A review of the literature, covering the period from 1980 to 2008, for the purpose of this study is presented.

The use of CC resin for custom trays has a number of disadvantages such as: polymerization shrinkage[9,17], vapour emission, toxicity, residual monomer, adverse tissue reactions and related diseases.[11-13,15,16,18,19] The introduction of LC resin for custom trays addressed some of these disadvantages. Khan & Geerts (2008) reported on the user-friendliness and hazardous effects in a training environment.[20]

They found that the LC material compared favorably with the CC product because it saved time and eliminated some hazardous effects associated with the CC material. Earlier studies also reported on its advantages such as fewer hazardous effects,[21,22] short preparation time, ease of use, good accuracy, strength and rigidity, uniform thickness, and good dimensional stability.[6,22-25] However, there are some disadvantages such as the additional expense of a special light polymerizing unit, stickiness on the surface once cured, poor finish and the hardness of the material making it more difficult to trim.[20-24]

Dimensional stability refers to maintaining the size and shape of a material. Several researchers reported on polymerization shrinkage and the lack of dimensional stability of CC resin tray material.[6,9,17,25-28] Therefore, a waiting period is recommended between fabrication and use.[6,9,17,21,25-28]

Fracture toughness is the ability to absorb energy without fracture. Fracture toughness is expressed as the stress intensity factor (Kic) and gives the intrinsic characteristic of a material concerning its resistance to crack.[29] It is a good indicator of the material's clinical behavior and for comparing materials.[30,31]

The *flexural strength* (FS) of a solid material is defined as its ability to resist deformation under load.[31,32] During

* BChd, PDD, MSc.
[†] BChd, PDD, MChD

removal from the mouth, custom trays are subjected to forces. Dental impression trays should be sufficiently rigid to resist permanent deformation when used with a high viscosity impression material to avoid potentially unreliable results.[33]

The purpose of this study was:

1) to assess the dimensional stability of the LC resin custom tray material

2) to compare the resistance to crack propagation of the LC and CC resins

3) to compare the strength and stiffness of the two materials

The null hypotheses were:

1) LC acrylic resin is not a dimensionally stable material

2) There is no difference in fracture toughness between the LC and CC materials

3) (a) The FS of a CC and LC PMMA does not differ and

   (b) None of the LC or CC materials exhibit plastic deformation.

MATERIALS AND METHODS

The research proposal was approved by the research and ethical committee of the University of the Western Cape.

For *dimensional stability* testing, 20 LC acrylic resin (Megatray®, Megadent, Radeberg, Germany) specimens with dimensions 2 x 4.2 x 20 mm were fabricated using a custom made perspex template.[30,34] (Figure 1) The template was lined with a thin layer of petroleum jelly (Blue Seal®, Johnson's, Cape Town, South Africa) and filled with a strip of LC resin. The cover of the template was placed over the mold. The specimen was compressed using hand pressure and the excess material removed before the template was closed. The specimens were light-polymerized (Megalight MINI®, Megadent, Radeberg, Germany) for 3 min. After polymerization, the template was disassembled, the specimen removed and placed in the light-polymerization unit for a further 3 min. The light unit specifications were as follows:

230 V, 50 Hz and 28 W. All specimens were examined under a light microscope (Wild, Heerbrugg, Switzerland) at a 10 x magnification. Those with visible defects were discarded and replaced. Within 30 min of polymerization, the length of each specimen was measured 3 times with a digital caliper (Power Seller®, Toronto, Canada) up to 0.01decimal. The averages of the 3 measurements for each specimen were used to determine *shrinkage* by subtracting it from 20 mm, which was the length of the template. This measuring protocol was repeated at 1hr, 24 hrs, 36 hrs and 48 hrs. Median, minimum, maximum shrinkage values and first and third quartiles for each time interval were determined. The medians for each time interval were compared using the Wilcoxon Rank Sum test. A p-value of less than 0.05 was regarded as significant.

For *fracture toughness* testing, 20 specimens from the same LC resin and a CC resin (Excel®, Wright Health group, UK) each were fabricated using the same perspex template. A steel blade was inserted inside the template to create a 3 mm notch on one side of each of the LC and CC specimens. (Figure 2) The LC specimens were shaped as explained in the previous paragraph. For the CC specimens, the material was handled following the manufacturer's specifications. All specimens were inspected for flaws. All specimens were placed on a support with a span of 17 mm and subjected to a 3-point bending test using a universal testing machine (Model 1446, Zwick, Germany) with 0.5mm/min crosshead speed and 5Kg loading cell. The load was applied in line and opposite the notch in a 3-point bending mode. The force (N) at fracture was used to calculate fracture toughness (Kic in MPam$^{0.5}$) using the formula[30]:

$Kic = (PL/bw^{1.5}) \, f \, (a/w)$, with $f(a/w) = 3/\alpha(a/w)^{0.5} \, 1.99-(a/w)(1-a/w)x[2.15-3.93a/w+2.7(a/w)^2]$, $\alpha = 2(1+2a/w) \, 91-a/w)^{1.5}$, Kic = stress intensity factor, w = width of specimen, b = thickness of specimen, a = depth of crack, P = load at fracture, L = span.

The mean, median and standard deviations for each group were determined. The Wilcoxon Sum Rank test was utilized to compare the Kic of the two groups. The distribution of forces was observed with the stem-and-leaf statistical method and interpreted using histograms and probability density estimates of frequency.
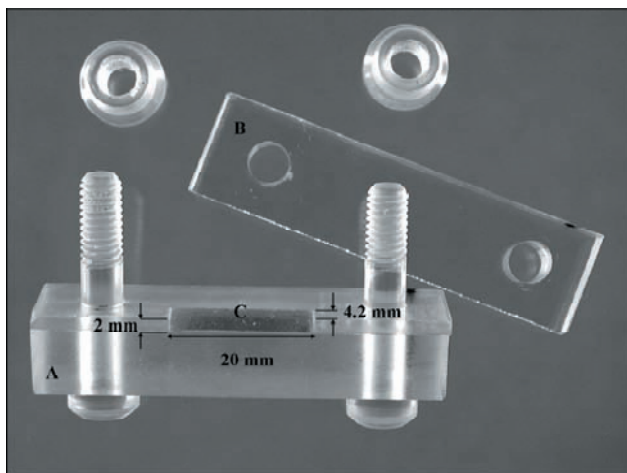

Figure 1. *The perspex mold, consisting of a base (A) and cover (B) that could be held together by means of 2 screws, C = specimen.*
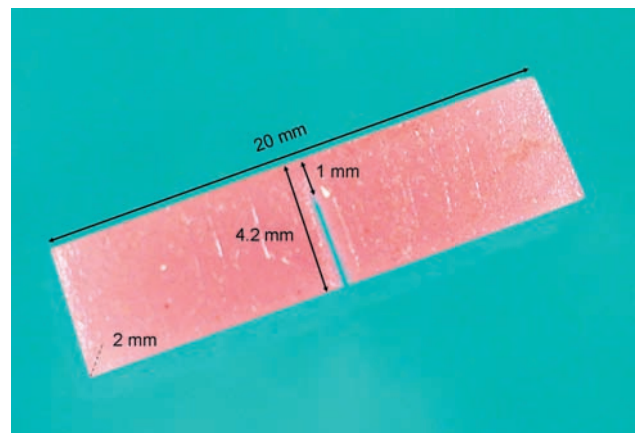

Figure 2. *Light-cured acrylic resin specimen with dimensions for fracture toughness test*

For *flexural strength* testing, 20 specimens of the same LC and CC materials as discussed previously were made using the same template, but without the blade creating a notch. All specimens were subjected to 3-point bending using a simple compression test using the universal testing machine. A centrally located load was applied until the specimens fractured. The maximum force (in N) was recorded and presented by the test Expert 11.2 software program attached to the universal testing machine. This maximum force was used to calculate the FS in MPa using the following formula[32]:

$$FS = \frac{3F_{max}\,l}{2\,b\,h^2},$$

with F_{max} being the maximum force registered during testing, l = support span, b = width of specimen and h = height of specimen.

The mean and standard deviation of the FS for both groups was calculated and statistically analyzed using the single ANOVA test. A p-value of <0.05 was considered significant. The CC group was accepted as the control group.

RESULTS

The medians of the average linear shrinkage values for the LC material were as follows: at 30 min: 0.23 mm, at 1hr: 0.25 mm, at 24 hrs: 0.20 mm, at 36 hrs: 0.27 mm and at 48 hrs: 0.28 mm. Compared to the standard (20 mm), shrinkage is significant for all time intervals ($p<0.05$). Although an

increase in shrinkage was noted over time, the difference among time intervals was not significant ($p>0.05$).

The descriptive statistics for the fracture toughness are shown in Table I. The Kic for the LC group ranged between 21.46 and 105.81 MPam$^{0.5}$, and for the CC group between 0 and 17.35 MPam$^{0.5}$. The difference between the median Kic values of the 2 groups was significant ($p<0.05$). The highest Kic value for the CC group is lower than the lowest Kic value for the LC group. (Table II)

For FS, 1 LC specimen was damaged during fabrication and removed from the experiment. The difference between the mean FS for the control group (54.9 MPa) and the test group (104.9 MPa) was significant ($p<0.0001$). The highest FS value for the control group (62.6 MPa) was lower than the lowest FS value of the test group (88.1 MPa). For 84% of the test group specimens, the maximum force (F_{max}) was the same as the breaking force; for the control group it was 20% of the specimens.

The relationship of F_{max} to the difference of F_{max} and force at breakpoint ($F_{\neq}$) is shown in Figure 3 for the CC material. A scatter plot showing the relationship between FS and highest force for both materials is shown in figure 4.

DISCUSSION

LC material is a *dimensionally stable* material after polymerization, thus negating the first hypothesis. This study measured linear shrinkage and the results showed that

Table 1. *Descriptive statistics for fracture toughness (MPam$^{0.5}$) and flexural strength (MPa)*

	Fracture Toughness		Flexural Strength	
Group	CC (control)	LC (test)	CC (control)	LC (test)
n	17	20	20	19
Mean	6.93	65.64	54.9	104.9
Median	7.00	67.43	55.0	105.3
Minimum	0.00	21.46	44.2	88.1
Maximum	17.36	105.82	62.6	118.3
Range	17.36	84.36	18.3	30.2
Standard deviation	4.98	22.26	4.4	8.7
Coefficient of variation (%)	71.86	33.91	7.9	8.3

Table 2. *Stem – and – leave diagram for fracture toughness (K_{IC} in MPam$^{0.5}$) of CC and LC materials*

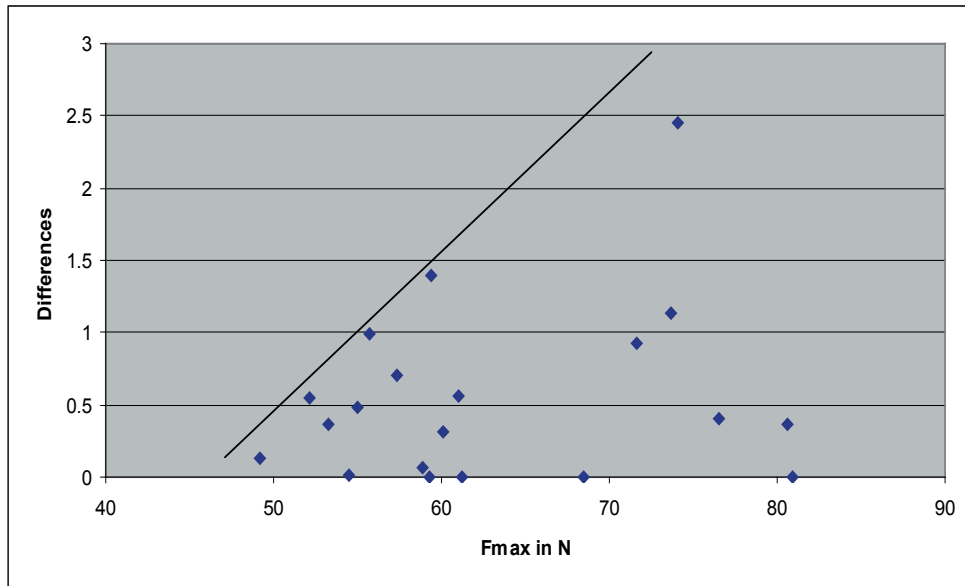|	CC		LC
Stem	Leaves	Stem	Leaves
0	00002 34677 7899	0	
1	01223 7	1	
2		2	15
3		3	8
4		4	7
5		5	4458
6		6	04
7		7	145
8		8	00458
9		9	5
10		10	6

Figure 3. *Scatter plot of the relationship of the difference in F_{max}-$F_{\#}$ to F_{max} for CC material*
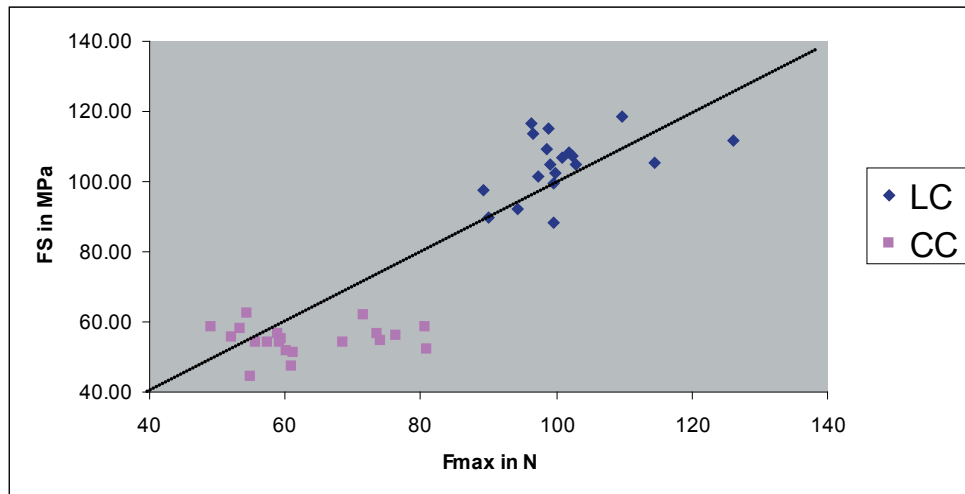

Figure 4. *Series scatter plot demonstrating the relationship of the flexural strength to F_{max} for the LC and CC resins*

significant shrinkage happens during polymerization. After completion of light-polymerization, no significant shrinkage occurs. These results are in agreement with previous findings.[6,23,24] The clinical significance of this finding is that trays made from LC material can be used immediately after polymerization. This is in contrast with CC tray material where a waiting period is recommended between fabrication and clinical use of the tray.[6,9,17,25-27]

A limitation of this study is that only linear shrinkage was measured as the rectangular specimens had standardized dimensions. Clinically, trays are arch-shaped. The thickness of a tray may also vary. This could influence the shrinkage in the different regions of the tray as stated in previous research on the CC material.[9,17] This could be investigated further.

There is a significant difference in the *fracture toughness* between the LC and CC materials countering the null hypothesis 2. The LC resin has a higher resistance against crack propagation than the CC product. This may be of

importance when a perforated tray is made. Perforations may be the clinical equivalent to the pre-crack of the test specimens. Four specimens in the CC group had no resistance against crack propagation. It is recommended that LC material is used whenever a perforated tray is indicated. Only one thickness of specimens was used in this experiment as the LC material comes in a preformed wafer. The influence of thickness of specimens on fracture toughness was not tested and could be investigated further.

Null hypothesis 3a cannot be supported. The LC material has a significantly higher FS than the CC material. These results confirm the findings by Breeding *et al.* (1994) who reported a small though significant difference in FS between the LC and CC materials.

Null hypothesis 3b can be partially supported. All specimens from the CC group showed plastic deformation before breaking. However, the LC resin behaves like a brittle material: the F_{max} and $F_{\#}$ were the same for 84% of the specimens. This is in conflict with the statement by

Breeding *et al.* (1994) who reported that all resins used to make custom impression trays exhibit plastic deformation at some force value. Conflicting findings among studies may be the result of using different commercial products. Comparing physical properties of generic groups of materials by using one commercial product representing a generic group must be done with caution.

The method of failure of the specimens is demonstrated by means of scatter plots. For higher F_{max} values, the ceiling of the differences indicated by the line on the plot also increases (Figure 3). This means that the stronger specimens within the CC group still have proportionally plastic deformation. This is in contrast to the LC material where a higher F_{max} does not seem to have an influence on the difference between F_{max} and $F_{\#}$. This difference is very small (0) for both lower and higher strength specimens. This is indicative of a brittle material: the material breaks at F_{max}, without plastic deformation.

Figure 4 displays the relationship between FS and F_{max}. Here, once again, a clear difference is noticed. For the CC material the dots are spread horizontally. The resistance against bending does not increase as the F_{max} increases (the stronger specimens in the group also bend). In contrast, for the LC group, the FS increases together with the F_{max} as reflected by a diagonal spread of dots.

It is recommended that the stronger material is selected when the strength of the tray is

compromised by the presence of perforations, for thin trays, or when high removal forces are anticipated, when medium bodied impression materials are used or when large undercuts are present. All CC specimens displayed plastic deformation. Plastic deformation of a custom tray is not noticeable clinically and may lead to inaccurate casts and prostheses.

CONCLUSIONS

1. LC tray material is dimensionally stable after completion of polymerization and can be used immediately.

2. LC tray material has a significantly higher resistance against crack propagation compared to the CC material. For thin or perforated trays LC material is recommended over CC material.

3. The LC tray material has a significantly higher resistance against bending compared to the CC material. The LC material does not show plastic deformation before fracturing but the CC material show slight deformation before fracturing.

ACKNOWLEDGEMENTS

ADDRESS FOR CORRESPONDENCE

Khan SB, BChD, PDD, MSc. Senior Lecturer, Department of Restorative Dentistry, University of the Western Cape, Private Bag X1, Tygerberg 7505. E-mail: skhan@uwc.ac.za

REFERENCES

1. Burns, J., Palmer, R., Howe, L, and Wilson, R. Accuracy of open tray implant impressions: an in vitro comparison of stock versus custom trays. *J. Prosthet. Dent.*, 2003; **89**:250-5.

2. Hyde,T.P. and Mc Cord, J.F. Survey of prosthodontic impression procedures for complete dentures in general dental practice in the United Kingdom. *J. Prosthet. Dent.*, 1999; **81**:295-9.

3. Millstein, P., Maya, A. and Segura, C. Determining the accuracy of stock and custom tray impression/ casts. *J. Oral Rehabil.*, 1998; **25:**645-8.

4. Castellani, D. and Basile, M. An alternative method for direct custom tray construction using a visible light-cured resin. *J. Prosthet. Dent.*, 1997;**7 8**:98-101.

5. Ogden, A.R., Siddiqui, A.A. and Basker, R.M. Disposable trays for complete denture construction: a dimensional study of a type frequently used in the UK and its suitability for the edentulous population. *Br. Dent. J.*, 1994; **176**:303-9.

6. Wirz, J., Jaeger, K. and Schmidli, F. Light-Polymerized Materials for Custom Impression Trays. *Int. J. Prosthodont.*, 1990; **3**:64-71.

7. Gordon, G.E., Johnson, G.H. and Drennon, D.G. The effect of tray selection on the accuracy of elastomeric impression materials. *J. Prosthet. Dent.*, 1990; **63**:12-15.

8. Valderhaug, J. and Floystrand, F. Dimensional stability of elastomeric impression materials in custom made and stock trays. *J. Prosthet. Dent.*, 1984; **52**:514-7.

9. Rueda, L.J., Sy-Munoz, J.T., Naylor, W.P., Goodacre, C.J. and Swartz, M.L. The Effect of Using Custom or Stock Trays on the Accuracy of Gypsum Casts. *Int. J. Prosthodont.*, 1996; **9**:367-73.

10. Pilcher, E.S. Draughn, R.A. Evaluation of polycapriolaitone custom tray material. *J. Prosthodont.*, 1993; **2**:174-7.

11. Scott, A., Egner, W., Gawkrodger, D.J., Hatton, P.V., Sherriff, M., van Noort, R., Yoman, C. and Grummitt, J. The national survey of adverse reactions to dental materials in the UK: a preliminary study by the UK Adverse Reactions Reporting Project. *Br. Dent. J.*, 2004; **196**:471-7.

12. Jorge, J.H., Giampaolo, E.T., Machado, A.L. and Vergani, E.C. Cytotoxicity of denture base resins: A literature review. *J. Prosthet. Dent.*, 2003; **90**:190-3.

13. Leggat, P.A. and Kedjarune, U. Toxicity of methyl methacrylate in dentistry. *Int. Dent. J.,* 2003;**53**: 126-31.

14. Thongthammachat, S., Moore, B.K., Barco, M.T., Hovijitra, S., Brown, D.T. and Andres, C.J. Dimensional accuracy of dental casts: influence of tray material, impression material, and time. *J. Prosthodont.,* 2002; **11**:98-108.

15. Hochman, N. and Zalkind, M. Hypersensitivity to methyl methacrylate: Mode of treatment. *J. Prosthet. Dent.*, 1997; **77**:93-6.

16. Pettersen, A.H. and Jacobsen, N. Perceived side effects of biomaterials in prosthetic dentistry. *J. Prosthet. Dent.*, 1991; **65**:138-44.

17. Fehling, A.W., Hesby, R.A. and Pelleu, G.B. Dimensional stability of autopolymerizing acrylic resin impression trays. *J. Prosthet. Dent.*, 1986; **55**:592-7.

18. Rajaniemi, R. and Tola, S. Subjective symptoms among dental technicians exposed to tray methyl methacrylate. *Scand. J. Work Environ. Health*, 1985; **11**:281-6.

19. Seppäläinen, A.M. and Rajaniemi, R. Local neurotoxicity of methyl methacrylate among dental technicians: *Am. J. Ind. Med.*, 1984; **5**:471-7.

20. Khan, S.B. and Geerts, G.A. The use of light-cured acrylic resin for custom trays by undergraduate dental students: a survey. *S.A.D.J.*, 2008; **63**:86-92.

21. Baker, P.S. and Frazier, K.B. Water immersion procedure for making light-cured custom trays with wax spacers. *J. Prosthet. Dent.*, 1999; **82:**714-5.

22. Brown, J. and Kerr, W.J. Light-curing acrylic resin as an orthodontic baseplate material. *Quintessence Int.*, 1998; **29**:508-12.

23. Ling, B.C. A three-visit, complete-denture technique utilizing visible light-cured resin for tray and base plate construction. *Quintessence Int.,* 2004; **35**:294-8.

24. Smith, P.W., Richmond, R. and Mc Cord J.F. The design and use of special trays in prosthodontics: guidelines to improve clinical effectiveness. *Br. Dent. J.*, 1999; **187**:423-6.

25. Breeding, L.C., Dixon, D.L., and Moseley, J.P. Custom impression trays: Part I--Mechanical properties. *J. Prosthet. Dent.,*1994; **7**:31-4.

26. Burton, J.F., Hood, J.A.A., Plunkett, D.J and Johnson, S.S. (1989) The effects of disposable and custom-made impression trays on the accuracy of impressions. *J. Dent.*, **17**:121-123.

27. Anderson, G.C., Schulte, J.K. and Arnold, T.G. Dimensional stability of injection and conventional processing of denture base acrylic resin. *J. Prosthet. Dent.*, 1988; **60**:394-398.

28. Goldfogel, M., Harvey, W.L. and Winter, D. Dimensional change of acrylic resin tray material. *J. Prosthet. Dent.*, 1985; **54**:284-6.

29. Phillips**,** R.W. *In: Skinner's Science of Dental Materials*. 8th ed. Philadelphia; W.B. Saunders Co; 1982.

30. Bonilla, E.D., Yashar, M. and Caputo, A.A. Fracture toughness of nine flowable resin composites. *J. Prosthet. Dent.*, 2003; **89**:261-267.

31. Gegauff, A.G. and Wilkerson, J.J. Fracture Toughness Testing of Visible Light- and Chemical-Initiated Provisional Restoration Resins. *Int. J. Prosthodont.,* 1995; **8**:62-8.

32**.** www.matweb.com, accessed data, 2007.

33**.** Cho, G.C. and Chee, W.W. Distortion of disposable plastic trays when used with putty vinyl polysiloxane impression materials. *J. Prosthet. Dent.*; 2004; **92**:354-8.

34. *Annual Book of Standards (ASTM)*, Standard E399-90 for Fracture Toughness test. West Conshocken (PA):1990, p13-15.