Effect of poly propylene fibers incorporation and their oxygen plasma treatment on tensile strength, wettability and wear resistance of heat cure denture base acrylic resin

Hasanain K.A. Alalwan, B.D.S. M.Sc. (1)

ABSTRACT

Background:Recently, Poly propylene fibers with and without plasma treatment have been used to reinforce heat cure denture base acrylic but, so far some of properties like tensile strength , wettability and wear resistance not evaluated yet, the aim of the study is to clarify the influence of incorporation of treated and untreated fibers on these properties.

Materials and methods: Twenty one specimens were fabricated for every tested property(tensile strength, wear resistance and wettability) that classified into three groups(control, untreated poly propylene fibers reinforced specimens and Oxygen plasma treated group)and for each test seven samples were used(n=7). Tensile strength was tested using Instron universal testing machine, wear resistance was evaluated by pin on disk wear measurement method while, a digital microscope supplied with high resolution camera was utilized to measure the contact angle reflecting wettability grade. One wayANOVA table and LSD were used to analyze the results.

Results: The tensile strength showed a paradoxical effect, plasma treated samples group demonstrated a negative influence in contrary, to the untreated group that revealed positive high significant impression. The plasma treated group had manifested a- positive significant difference regarding wear resistance whilst, the beneficial effect of treated and untreated Poly propylene fibers addition was obvious with high significant difference.

Conclusion: Incorporation of O_2 plasma treated and untreated poly propylene fibers to heat cure poly methyl methacrylate resin was beneficial regarding the tested properties except for addition of plasma treated Poly propylene fibers on tensile strength.

Key words: Poly propylene fibers, tensile strength, wettability, wear resistance, denture base. (J Bagh Coll Dentistry 2014; 26(4):32-38).

الخلاصة

الخلفية:حديثا الياف البولي بروبيلين مع و بدون معالجة بلازما الاوكسجين قد استخدمت في تقوية الراتنج الاكريلي الحراري لقاعدة الطقم لكن لحد الان لم يختبر تاثيرها على قوة الشد وقابلية الترطب ومقاومة البلى.

المواد و الاساليب:احدى و عشرين عينة قد اختبرت لكل صفة من الصفات الثلاثة بواقع سبعة نماذج اختباريةلكل من مجموعة السيطرةو مجموعة النماذج المدعمة بالالياف المعالجة ببلازما الاوكسجين والمجموعة الاخيرة للالياف غير امعالجة.اختبرت قوة الشد بجهاز الانسترون و اختبرت قابلية الترطب بمايكروسكوب رقمي وفحصت مقومة البلى بطريقة المسمار على القرص.**النتائج:**اظهرت النتائج تباينا واضحا عند فحص قوة الشد لصالح اضافة الالياف غير المعالجة بينما بينت تاثير سلبي للالياف المعالجة اما ما يخص الصفتين الأخرتين فقد اظهرتا تأثرا ايجابيا خصوصا في صفة قابلية الترطيب.

الاستنتاج:مع محدودية البحث يستنتج بأن اضافة الالياف المعالجة و غير المعالجة اثر ايجابيا بالصفات المدروسة في ما عدا قوة الشد مع الالياف المعالجة

INTRODUCTION

Fiber reinforced polymer resin composites have sorted several types of fibers with diverse traits. Carbon fibers revealed poor esthetics, glass fibers manifested hydrolytic degradation and corrosion leading to strength reduction and destruction of polymer fiber interface [1,2]. Poor esthetics and polishibility were apparent with aramid fibers [3].Ultra high modulus Poly ethylene Fibers reinforcement have been researched for several years and these studies showed controversial reinforcing effects [4-6]. While, poly propylene fibers (PP fiber) has been harnessed to reinforce denture base acrylic resin recently,Polypropylene fiber is considered as one of the polyolefin synthetic fibers that characterized with strength, staining and abrasion resistance [7]. Impact strength was the most obvious improved property moreover, Oxygen plasma treatment have beenrelied on to enhance fiber-matrix impregnation [8,9].

The influence of PP fiber incorporation on tensile strength, wear resistance and wettability have not tested yet. A low-temperature glow-discharge Oxygen plasma impact on the structure and properties of exposed materials especially polymers results in etching and changes in a micro-structure of the surface. As a consequence of the change in a surface layer structure, a number of functional properties, in particular, adhesion, sorption and tribology are changed [10].

Noort have attributed inclination of dentures to fracture to low tensile strength which is of no more than50 MPa, low elastic and flexural modulus and lack of fracture toughness [11]. Wear resulted from removal and relocation of materials via the contact of two or more materials leading to material loss. Wear resistance is deemed as one of the properties that be judiciously developed by composite [12]. In bite splint fabrication, heat cure acrylic is utilized where high wear resistant material is usually preferred to keep the new occlusal relation and withstand opposing natural or artificial dentition [13]. Denture base material wettability play an effective role in denture retention, complete wetting of denture surface increase the capillary force therefore, raising denture retention in static and dynamic situations [12]. In this study, the reinforcing effect of poly propylene fibers incorporation to poly methyl methacrylate and their Oxygen plasma

(1)Assistant Lecturer. Department of Prosthodontics, College of Dentistry, University of Baghdad

treatment effect on tensile strength, wear resistance and wettability have evaluated.

MATERIALS AND METHODS

Incorporation of (6 mm length) 2.5 % (by weight) poly propylene fibers (PP fibers) (Cracecemfiber®) (figure1) to poly methylmethacrylate heat curepowder (PMMA)(SUPERACRYL® PLUS, Czech Republic-cross linked) in this study was according to recent studythat have showed an incorporation of that percentage had the best effect regarding impact and transverse strengths which might considered main properties in measuring the strength of materials [9].

Figure 1: Poly propylene fibers

The specimens were grouped to three groups for each one of the three tests (tensile strength, wear resistance and wettability test) of this study :control group, specimens with untreated PP fibers and the third group was specimens with Oxygen plasma treated PP fibers whereas the number of specimens for each group was seven(n=7).PP fibers was treated with Oxygen plasma usingDC- glow discharge system device with 6 minutesexposure time(figure2),gas pressure was limited to 0.5 x10-^{1}mlbar while the flow rate of gas was 10 ml/ min using flowmeter (Ministry of Science and Technology-Iraq, physics department).

FTIR (Fourier Transform Infrared Spectrophotometer, SHIMADZU, 8400SJapan) (figure3) was utilized to find out and identifyfunctional groups PP fibers surface involvement (figure4a,b). Test specimens elaboration wasdone via making plastic patterns cut with highly precise laser turning machine. Conventional flasking method has undertaken after mould preparation to form specimens.All the specimens for all the three tests were finished and polished.

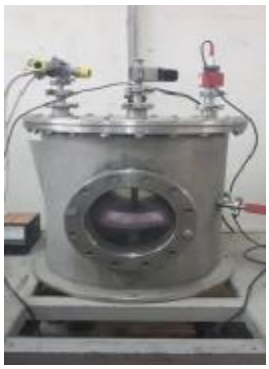

Figure 2: Plasma chamber

Figure 3: FTIR device

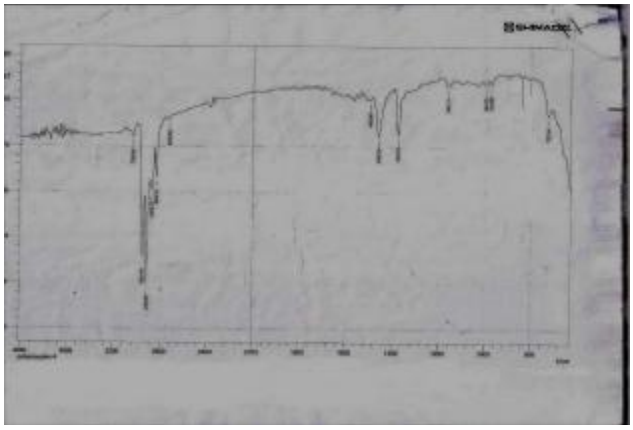

Figure 4a: FTRI of untreated PP fibers.

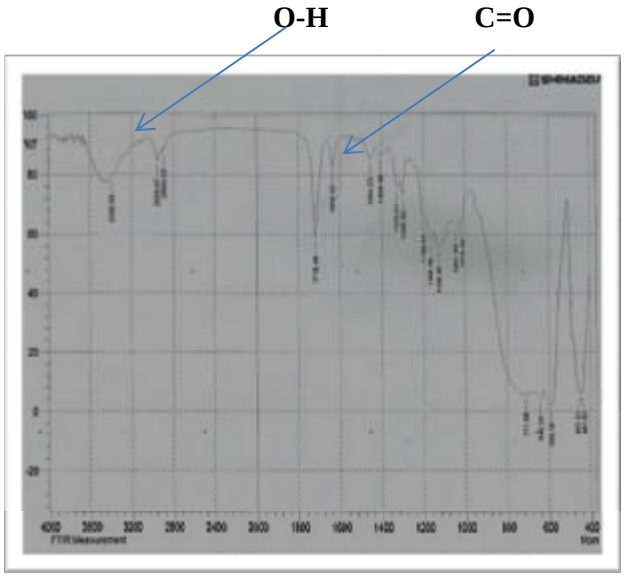

Figure 4b: FTIR of treated PP fibers with (C=O, 1719) and (O-H, 3382) functional groups.

Incorporation of polypropylene fibers

2.5% by weight added to the subtracted weighed powder. The required weight of the fiber and powder was measured by electronic balance (with accuracy 0.0001g).The weight of fibers was secured by the following equation:

Fiber reinforcement percentage % = weight of fiber/weight of fiber+ weight of matrix. Powder and PP fibers mixing wereachieved using mortar and pestle tilluniform mixture was obtained. Mixing with monomer was done incrementally for throughout dispersion of the fibers.

Tensile strength test

Dumbbell shaped specimens were fabricated according to ASTM specification D-638M (1986) with dimensions asexplicitly illustrated in figure 5.

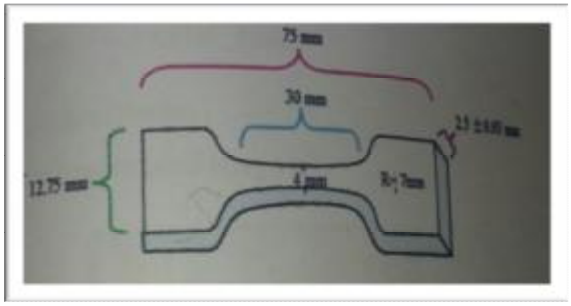

Figure 5: Dimensions of tensile test pattern.

Afterwards, they were conditioned in distilled water for two days at room temperature25c°±2before testing according to ADA specifications. The testing procedure was accomplished using Instron universal testing machine (LARYEE, make test easy, china) with crosshead speed 0.5 mm/min and maximum loading of 20Kg. Tensile strenfth was calculated electronically via the software of the testing machine.(figure6)

Figure 6: Tensile strength PP fiber reinforced specimen after submitting to the test.

Wear resistance test

Pin on disk wear testing device was used that recognized with high reproducibility of results [14, 15], designed at University of Technology, Material engineering department, resistance laboratory-Iraq. The specimens were cylindrical in shape with dimensions of 20mm length and 10mm diameter according to the device requirement (figure7). The pin was the held specimen while the disk was stainless steel wheel which revolve 950 r/min, the specimen was weighed before and after the testing procedure, after securing the specimen to the holder and putting of 10N load on the horizontal arm, the device switched on for 10 minutes (wear testing time)[16]. The distance between the center of the disk and center of the specimen was 65mm.the wear resistance was calculated with the following equation: wear resistance (gr/mm) =change in weight/slide distance (slide distance=2π×radius distance between centers of disk and specimen×number of cycles ×time of test) [16]. The disk was cleaned with abrasive grit paper after each test (figure8).All specimens were immersed in distilled water for 48 hours before testing.

Figure 7: Wear specimens

Figure 8: Pin on disk mould with held specimen.

Wettability

Contact angle measurement was harnessed to determine the wettability; the angle was between the base of the sessile drop and the tangent line contacting the solid, liquid and air simultaneously. Dispersing of distilled water 10µLatthe center of the fabricated sample using pipette.Dimensions of the sample 8×30×2mm width, length and thickness respectively [17].Static sessile drop method was utilized in this study. As the water dispersed wait for 5 minutes to allow the drop to be in status of equilibrium. Measurement of the contact angle was accomplished employing a digital microscope (Dino-lite digital microscope pro -Taiwan) at magnification 45× supplied with camera (high resolution 1024×768 pixel) and software (Dino capture2.0 Version 1.3.3.) granted

a completeand precision analysis to the contact angle.(figure9)

Figure 9: Digital microscope with specimen.

Descriptive statistical analysis involving: arithmetic mean, standard deviation and standard error in addition to inferential statistical analysis including: F- test by Analysis of Variance andleast significant difference (LSD) was conducted for further verification. P > 0.05 NonSignificant (NS), P≤ 0.05Significant(S) and P≤0.001 High Significant (HS).

RESULTS

Tensile strength

Untreated Polypropylene fiber reinforced samples showed the higher mean (58.2571)while the treated revealed the lowest (53.6857) as illustrated in table1.ANOVA table- in table 2- displayed a statistical significant difference (P=0.003) among the studied groups. Table 3 demonstrated a positive significant effect of the untreated PP fiber reinforced samples over the control, in opposite to non-significant relation of control to treated PP fiber reinforced samples, while a high significant difference (P=0.001) between treated and untreated PP fiber samples in favor of untreated one.

Table1: Descriptive statistics of tensile strengthtest Mpa among the studied groups.

Group	N	Mean	S. D.	S. E.
Control	7	54.458	2.2063	0.8339
Untreated PP F	7	58.257	2.9102	1.0999
Plasma treated PP F	7	53.685	1.4690	0.5552
Total	21			

Table2: ANOVA table of tensile strength testamong the studied groups.

F	P-value	Sig.
8.114	0.003	S

Table 3: LSD of tensile strength test groups

Study group	Study group	Mean Difference	P-value	Sig.
Control	**Untreated PPfiber**	-3.79857	.006	S
Control	**treated PPfiber**	0.77286	.533	NS
Untreated PP fiber	**Plasma treated PPfiber**	4.57143	.001	HS

Plasma treated PP fiber reinforced specimens exhibited the highest wear resistance because they showed the lowest weight loss per millimeter (0.000010),whilst the control manifested the lowest wear resistance(0.000012) moreover, ANOVA table presented a significant difference among tested groups(P=0.030) as shown in table4 and table 5.Multiple comparison with LSD(table6) revealed a non-significant difference between groups except between control and plasma treated PP fiber reinforced specimens(P=0.009).

Table 4. Descriptive statistics of wear resistance (gm/mm) test among the studied groups.

Group	N	Mean	S. D.	S. E.
Control	7	0.000012	.0000008	.0000003
Untreated PP F	7	0.000011	.0000013	.0000005
Plasma treated PP F	7	0.000010	.0000018	.0000007
Total	21			

Table 5: ANOVA table of wear resistance test among the studied groups.

F	P-value	Sig.
4.311	0.030	S

Table 6: LSD of wear resistance test among studied groups

Study group	Study group	Mean Difference	P- value	Sig.
Control	**Untreated PPfiber**	.0000013	.097	NS
Control	**treated PPfiber**	.0000021	.009	S
Untreated PP fiber	**Plasma treated PPfiber**	.0000009	.259	NS

Wettability

Table 7 offers the effect of incorporation on the mean contact angle among studied groups, the highest mean was in control group so, represented the lowest wettability however, the Oxygen plasma treated PP fiber reinforced specimens showed the contrary. The evidence on the strong effect of PP fibers incorporation and their plasma treatment on wettability of PMMA has proved by ANOVA table and further affirmed statistically with LSD, where a high significant difference between each two different groups as illustrated in table 8 and table 9.

Table7: Descriptive statistics of wettability test among the studied groups.

Group	N	Mean	S.D.	S.E.
Control	7	45.6039	2.701025	1.020892
Untreated PP F	7	35.7269	3.355893	1.268408
Plasma treated PP F	7	27.8051	2.753189	1.040608
Total	21			

Table 8: ANOVA table of wettability test among the studied groups.

F	P-value	Sig.
63.887	.000	HS

Table 9: LSD of wettability test among studied groups

Study group	Study group	Mean Difference	P-value	Sig.
Control	**Untreated PP fiber**	9.877000	.000	HS
Control	**Plasma treated PP fiber**	17.798714	.000	HS
Untreated PP fiber	**Plasma treated PP fiber**	7.921714	.000	HS

DISCUSSION

The negative effect of plasma treatment to PP on the tensile strength was strong enough to clearly reduce it, it could be inferred to the water absorption of PP fibers was improved by plasma treatment. This fact was caused by the creation of polar C=O andO-H groups on the surface after plasma treatment.It happen due to plasma probably breaks the C–H and/or C–C bonds creating free radicals, which can react with the activated oxygen species in the discharge leading to the formation of these moieties, this is in agreement with Skacelova et al and Morent et al [18, 19].

Absorption of water by PMMA accomplished slowly over a period of time, essentially because of the polar properties of the resin molecules. High water uptake equilibrium can soften an acrylic resin because the absorbed water acts as a plasticizer and reduce the strength of the material [20]. The incidence of water uptake into PMMA networks are substantially controlled by resin polarity, affected by the concentration of polar groups available to form hydrogen bonds with water and network topology [21], therefore, incorporation of oxygen plasma treated poly propylene fibers to PMMA had increased the water absorption significantly [9] and PMMA tensile strength is negatively affected by water absorption and ambient moisture, this is in agreement with Ishiyama et al [22], in addition to the acrylic used in this study was of cross linked type that might exaggerate the water absorption [23]. Furthermore, a previous study conducted to review all the articles related to fiber reinforced denture base materials had noticed that plasma treatment for UHMPE fiber had not increased PMMA strength in comparison to untreated [2]. Generally, plasma treatment for fibers can lessen the tensile strength of the fibers themselves due to their loss of weight and diameter reduction [24,25].

On the other hand, two essential properties of PP fiber are moisture absorption very low capability and good toughness [26] thus, the incorporation of untreated PP fiber has increased the tensile strength while, the plasma treated was equivalent to control group where the benefit of PP fiber addition had cancelled after changing the surface of the fibers and making them more hydrophilic, that encouraged water absorption and weakened the material. Poor impregnation of the untreated fibers did not precipitate a negative

influence, it could be attributed to solicitude during fiber-powder blending and homogenous mixing with monomer that distribute the fibers and prevent their accumulation.

Wettability of acrylic reinforced with untreated and Oxygen plasma treated PP fiber was highly magnified, regarding the treated PP, it might be elucidated by increasing the water affinity of the PP fiber itself via plasma treatment this is in agreement with several researchers [27-29], that overshadowed on PMMA-PP fiber composite wettability and occurrence of new functional groups as annotated above guiding the change in a surface layer structure. Wettability of the untreated PP fibers incorporated samples was increased considerably because the addition of randomly oriented PP fibers elevates the surface roughness even non-significant statistically [9], the surface roughness and wettability are directly proportional [30], consequently, the untreated PP fiber samples wettability had raised.

High abrasion resistance of PP fiber [26] had increased the untreated PP fiber reinforced samples wear resistance yet, that not significant statistically however, after plasma treatment it significantly improved in comparison to control group and this may be attributed to formation of functional groups on the pendant methyl group of the isotactic PP fiber leading to increased crosslinking that decreased plastic flow which in turn increased the wear resistance and that was consistent with Kyomoto et al and Drobny [31, 32].

Resin composite capability to withstand wear relies on filler–matrix interactions and highly sensitive for spacing between them, the Oxygen plasma treatment had played that role and increased the wear resistance [33]. Finally, it can be concluded that incorporation of O2 plasma treated and untreated PP fibers to heat cure PMMA was beneficial regarding the tested properties except for addition of treated PP fiber on tensile strength.

REFERENCES

1. Vallittu PK. Compositional and weave pattern analyses of glass fiber in dental polymer fiber composites. J Prosthod 1998; 7: 170-6.
2. Vallittu PK. A review of fiber-reinforced denture base resin . J Prosthod 1996; 5(4): 270-6.
3. Jagger DC, Harrison A, Jandt K. The reinforcement of denture. J Oral Rehabil 1999; 26:185-94. (IVSL).
4. Geerts GAVM, Overturf JH, Oberholzer TG. The effect of different reinforcements on the fracture toughness of material for interim restoration. J Prosthet Dent 2008; 99: 461-7.
5. Uzun G, Hersek N, Tincer T. Effect of five woven fiber reinforcement on the impact and transverse strength of a denture base resin. J Prosthet Dent 1999; 81: 616-20.
6. Williamson DL, Boyer DB, Aquilino SA, Leary JM. Effect of polyethylene fiber reinforcement on the strength of denture base resins polymerized by microwave energy. J Prosthet Dent 1994; 72(6):635-8.
7. Sarja JK, Anna LL. Textile. 9th ed. New Jersey: Upper Saddle River; 2002. p. 109-13
8. Mowade TK, Dange ShP, Thakre MB, Kamble VD. Effect of fiber reinforcement on impact strength of heat polymerized polymethyl methacrylate denture base resin: in vitro study and SEM analysis. J Adv Prosthodont 2012; 4(1): 30-6.
9. Waffaa I. M. The effect of addition of untreated and oxygen plasma treated polypropylene fibers on some properties of heat cured acrylic resin (A comparative study). A master thesis, Department of prosthodontics, University of Baghdad, 2013.
10. Maximov A, Gorberg B, Titov V. Possibilities and Problems of Plasma Treatment of Fabrics and Polymer Materials. In: Textile Chemistry – Theory, Technology, Equipment (Ed. A.P.Moryganov). – New York: Nova Sci. Publishers, Inc., Commack; 1997. p. 225 –45.
11. Noort RV. Introduction to dental materials. 2nd ed. Else view Science Limited, Mosby; 2002. p.216.
12. Powers JM, Sakaguchi RL. Craig's restorative dental materials. 12th ed. St. Louis: Mosby Co.; 2006. p.78.
13. Widmalm SE. Use and abuse of bite splints. University of Michigan; 2004. p.1-14. www.yumpu.com/en/document/view/5110164/use-and-abuse-of-bite-splints (retrieved in 12-April-2014).
14. Prieto G, Faulkner M, Alcock JR. The influence of specimen misalignment on wear in conforming pin on disk tests. Wear 2004; 257(1-2): 157-66.
15. SaikkoV, Calonius O, Keranen J. Effect of counterface roughness on the wear of conventional and crosslinked ultrahigh molecular weight polyethylene studied with a multi-directional motion pin-on-disk device. J Biomedical Mater Res 2001; 57(4): 506-12.
16. Mustafa FM. Assessment of some mechanical properties of Imprelon and Duran thermoplastic biostar machine sheets in comparison with some types of acrylic resin. A master thesis, Department of prosthodontics, University of Baghdad, 2012.
17. Shaymaa HA. The effect of plasma treatment on the bonding of soft denture liners to heat cured acrylic resin denture base material and on some surface properties of acrylic resin polymer. A master thesis, Department of prosthodontics, University of Baghdad, 2012.
18. Skacelova D, Fialova M, Stahel P, Cemak M. Improvement of surface properties of reinforcing polypropylene fibers by atmospheric pressure plasma treatment. ICPIG (conference), Augt 28th - Sep 2nd, 2011; Belfast, UK, Topic No. D13.
19. Morent R, De Geyter N, Leys C, Gengembre L, Payen E. Comparison between XPS- and FTIR-analysis of plasma-treated polypropylene film surfaces. Surface and Interface Analysis 2008; 40: 597–600.
20. Barsby MJ. A denture base resin with low water absorption. J Dent 1992; 20: 240–4.
21. Malacarne J, Carvalho RM, de Goes MF, Svizero N, Pashley DH, Tay FR, Yiu CK, Carrilho MR. Water sorption/solubility of dental adhesive resins. Dent Mater 2006; 22: 973–80.
22. Ishiyama C, YamamotoY, HigoY. Effects of Humidity History on the Tensile Deformation Behaviour of Poly (methyl –methacrylate) (PMMA) Films. 2005 MRS Spring Meeting. http://journals.cambridge.org/action/displayAbstract

MRS Online Proceedings Library (retrieved 5/April/2014).
23. Armia T, Murata H., and Hamada T. The effect of cross-linking agent on the water sorption and solubility characteristic of denture base resin.J prosth. Dent 1996; 23: 476-80.
24. Yasuda T, Gazicki M, Yasuda H. Plasma polymerization and plasma treatment. J Applied Polymer Science. Applied Polymer Symposium 1984; 38: 201-14.
25. Kabajev M, Prosycevas I, Kazakeviciute G, ValieneV. Plasma Modification of Structure and some Properties of Polyethylene Therepthalate Films and Fibers. Material Science 2004;10(2):173-6.
26. Mandal J. Polypropylene Fiber and Its Manufacturing Process, Properties, Advantages, Disadvantages and Applications of Polypropylene Fiber.http://textilelearner.blogspot.com/2013/01/polypropylene-fiber-and-its.html.(retrieved 10-April-2014).
27. Morent R, De Geyter N, Gengembre L, Leys C, Payen E, Van Vlierberghe S, Schacht E. Thin films processing and surface engineering surface treatment of a polypropylene film with a nitrogen DBD at medium pressure. The European Physical Journal of Applied Physics 2008; 43(3): 289-94. (IVSL).
28. Wei Q, Qi Li, Wang X, Huang F, Gao W. Dynamic water adsorption behaviour of plasma-treated polypropylene nonwovens. Polymer Testing 2006; 25(5): 717–22. (IVSL).
29. Kang J, Sarmadi M. Plasma treatment of textiles-synthetic polymer-based textiles. AATCC Review 2004; 4 (11):29-33. (IVSL).
30. Kubiak KJ, Wilson M, Mathia TG, Carval Ph. Wettability versus roughness of engineering surfaces. Wear 2011; 271: 523–8.
31. Kyomoto M, Moro T, Konno T, Takadama H, Yamawaki N, Kawaguchi H, Takatori Y, Nakamura K, Ishihara K. Enhanced wear resistance of modified cross-linked polyethylene by grafting with poly(2-methacryloyloxyethyl phosphorylcholine).J Biomed Mater Res A 2007; 82(1):10-7.
32. Drobny JG. Ionizing radiation and polymers, principles, technology and applications. 1st ed. 225 Wyman St. Waltham AM.02541.USA; 2013. p. 104-5.
33. Zhou ZR, Zheng J. Tribology of dental materials: a review. J Physics Applied Physics 2008; 41:1-22.