IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)
e-ISSN: 2279-0853, p-ISSN: 2279-0861.Volume 21, Issue 1 Ser.10 (January. 2022), PP 15-21
www.iosrjournals.org

Effect of Reinforced Fiber Addition and Thermocycling on Impact Strength of Heat-Cured Acrylic Resin Denture Base

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Abstract:
Background: *Heat-Cured Acrylic Resin is one of the most commonly used materials for making denture bases. However, this material has low impact strength, causing the denture base to break easily when it hits the floor. This can be overcome by adding reinforcing materials in the form of E-glass fibers and polyethylene fibers because they have good aesthetics, are resistant to moisture and chemicals, and are easy to manipulate. As the length of use in the oral cavity, the denture base is exposed to food and beverages at different temperatures, which affects mechanical strength, especially impact strength.*
Purpose: *This study aimed to determine the effect of adding E-glass and polyethylene fibers to a heat-cured acrylic resin denture base on the impact strength with and without thermocycling, and also to determine the effect of thermocycling on the impact strength of a heat-cured acrylic resin denture base with added E-glass and polyethylene fibers.*
Materials and Methods: *This is an experimental laboratory study, 36 samples divided into 6 groups consisting of*
E-glass fiber, polyethylene fiber, and without fiber (with and without thermocycling) samples were each fabricated in Unit UJI Laboratorium Dental FKG USU. Measurement of impact strength using the Charpy Impact Tester. The effect of E-glass and polyethylene fibers addition on the impact strength of heat-cured acrylic resin denture base material without and with thermocycling analyzed with One Way ANOVA. The effect of thermocycling to impact strength of heat-cured acrylic resin denture base with and without adding reinforced fiber analyzed with T-independent Test. LSD analysis was then performed to see which fiber has the best effect on to impact strength of heat-cured acrylic resin.
Result: *The result showed there was an effect of E-glass and polyethylene fibers addition on the impact strength of heat-cured acrylic resin denture base material without and with thermocycling. There was a thermocycling effect to the impact strength value of heat-cured acrylic resin denture base material with and without added reinforce fiber with use 3000 cycles as the simulation of oral cavity condition for 3 years denture usage.*
Conclusion: *The significant effect of the impact strength of the denture base heat-cured acrylic resin given the addition of E-glass fiber and polyethylene fiber is still acceptable despite a decrease in the impact strength after thermocycling. The addition of E-glass fiber and polyethylene fiber to the heat-cured acrylic resin can increase the impact strength of the denture base and reduce water absorption.*
Key Word: *Acrylic Resin, reinforced material, E-glass, UHMWPE, impact strength, thermocycling*

Date of Submission: 06-01-2022 Date of Acceptance: 18-01-2022

I. Introduction

The denture base is the part of the denture that rests on supporting tissue has the function of replacing the lost alveolar bone, restoring facial esthetics, accepting functional loads, and distributing functional loads to the supporting tissues of the teeth, alveolar ridge, or abutment teeth and supporting the components of the denture.[1,2] The denture base must be good in terms of aesthetics, color stability, dimensional stability, and mechanical strength, easy to manipulate, non-irritating, affordable, and easy to repair when damage occurs.[2,3] In 1937 Dr. Walter Wright introduced polymethyl methacrylate (PMMA) or acrylic resin as a denture base material and until now it has become the material most often used in the manufacture of dentures. This material has several types based on their activation such as heat-cured acrylic resin, light-cured acrylic resin, and chemical cured acrylic resin.[4] Of the three types, Heat-cured acrylic resin is the most commonly used. Acrylic resin has the advantages of good biocompatibility, color, and texture resembling mucosa, easy to manipulate, non-toxic, non-irritating, good dimensional stability, relatively low water absorption, and good resistance to food and organic liquids.[1] Despite having many advantages, heat-cured acrylic resin has the disadvantage of low impact strength, which makes it easy for the denture to fracture when it hits the floor.[5]

Several studies have found that one way to increase the impact strength of heat-cured acrylic resin denture base materials is to add reinforcing fibers to the base. Types of fiber that can be used in denture bases are carbon fiber, aramid fiber, nylon fiber, fiberglass, polyethylene fiber, polyester fiber, and polypropylene fiber.[5] Of the various types of fiber, fiberglass and polyethylene fiber are the types that are often used because of their great aesthetics and good mechanical strength.[5] Ferasima R, et al. (2013) reported that glass fibers and polyethylene fibers could increase the impact strength of acrylic resin denture base.[6] Watri D (2010) reported that there was a significant increase in the impact strength of acrylic resin added with chopped strand glass fiber at concentrations of 1%, 1.5%, and 2%.[6] E-glass is the most widely used fiber due to its excellent transparency and can be easily adjusted to shape and size as required.[7] However, in the application of glass fiber and acrylic resin, it is necessary to add a silane coupling agent to increase adhesion and prevent voids in the matrix resin. Silane coupling agent as an adhesive material serves to bind the filler particles with the resin matrix so that it becomes more homogeneous and is also helpful for improving the mechanical and physical properties of the resin, as well as for stabilizing the hydrolytic prevention of water.[8] Rahamneh A (2009) stated that specimens containing woven polyethylene fibers had the highest impact strength, followed by specimens containing glass fiber and carbon fiber.[9] In adding polyethylene fiber to acrylic resin, plasma treatment of UHMWPE polyethylene fiber is required. This is due to the very strong intramolecular bond in the polyethylene fiber so that the resulting adhesion becomes poor and causes a gap between the fiber surface and the polymer matrix so that the resulting strength decreases.[9] One way to increase the adhesion of fibers to the polymer matrix is to use monomers known to improve mechanical interlocking by creating cracks and pits and surface roughness so that the adhesion and polymer matrix are maximally combined without any gaps between the fibers.[10,11]

According to ISO 1567, the denture base must not be less than 2×10^{-3}J/mm2. The higher value of the impact strength of the denture base, the better it will be to distribute the load to prevent fracture.[10] Along with use, the denture will be exposed to food at different temperatures which causes the aging process of the denture. To simulate the aging process according to conditions in the oral cavity is using thermocycling. The temperature used to simulate the conditions in vitro by thermocycling is 5°C - 55°C, 1000 cycles (1 year), and dwell time 60 seconds/cycle.[12,13,14] Thermocycling significantly reduces the mechanical strength (modulus elasticity, transversal strength, impact strength, fatigue strength) of polymeric materials, affects the hardness, absorption, solubility, and discoloration of a material due to loss of ethanol, plasticizer, and the occurrence of increased water absorption after the thermocycling procedure.[12,13,15] This can be prevented by adding reinforced fiber. Lim E (2017) reported that there was a significant difference in the impact strength value of heat-cured acrylic resin with the addition of woven polyethylene fiber Ribbon THM and Ribbon Ultra compared to the control group after thermocycling 3000 cycles.[16] Ariyani (2016) stated that RAPP which was carried out by thermocycling 2000 cycles without the addition of e-glass fiber showed a very significant difference when compared to the RAPP group which added 1% and 1.5% e-glass fiber.[17]

Based on the above, the researcher felt the need to evaluate the effect of the addition of chopped strand E-glass fiber and woven UHMWPE fiber with and without thermocycling on the impact strength of heat-cured acrylic resin denture base and to evaluate the effect of thermocycling with an impact strength value of heat-cured acrylic resin denture base material with and without added chopped strand E-glass fiber and woven UHMWPE polyethylene fiber

II. Material And Methods

This research is an experimental laboratory study with 36 samples of heat-cured acrylic resin, which were divided into 6 groups, namely, without reinforced fiber and without thermocycling, without reinforced fiber and with thermocycling, with addition chopped strand E-glass fiber and without thermocycling, with addition chopped strand E-glass fiber and with thermocycling, with addition woven UHMWPE fiber and without thermocycling and with addition woven UHMWPE fiber with thermocycling. The sample size is 80 mm x 10 mm x 4 mm (International Standards Organization No.179-A1:2005). The manipulation of chopped strand E-glass fiber of 3 mm size with 1,5% weight is carried out by immersing in the silane coupling agent (Ultradent®) for 40 minutes, then heat the fiber with 115ºC temperature for one hour. Inside the acrylic pot, the next step is to put the glass fiber on heat-cured acrylic resin denture base (Acron, GC, Japan) powder and then add monomer and stir until it becomes homogeneous, when acrylic enters the dough phase, the next step is to put it into a mold. For woven UHMWPE fiber (Bianinastro, Biancaden, Italy) manipulation; The first step, cut the fiber with a length of 80 mm, then soak the fiber in the monomer for 60 minutes in a container and drain it. The second step, mix the PMMA powder and monomer stirred until homogeneous, then put the acrylic dough inside 1/3 of the mold. The soaked polyethylene fiber is placed using tweezers into the mold in the center position. When the acrylic enters the dough phase, then put the remaining dough into the mold. Cover the cuvette with a plastic sheet. The upper and lower cuvettes are attached and then pressed gently with a hydraulic press with 1000 psi and 2200 psi pressure. Remove the cuvette from the press and install and screw the cuvette for 30 minutes. Then put the cuvette in waterbath (Filli Manfredi, Italia) with distilled water, set the temperature and time on the waterbath with a temperature of 70ºC for 90 minutes. After 90 minutes, set the temperature and time on the waterbath with a temperature of 100ºC for 30 minutes, after that the cuvette was left in the waterbath until the water reached room temperature.

The impact strength testing is done in Impact and Fracture Research Center at University of Sumatera Utara, Indonesia, and thermocycling testing in Faculty of Dentistry in Chulalongkorn University, Bangkok, Thailand. Thermocycling (TC 301, 0-999,999 cycle, Thailand) is carried out at 3000 cycles with a temperature of 5-55ºC for a total of 60 seconds, which is calculated as 1 cycle. Impact strength testing was performed using Charpy Impact Tester. The sample is then placed in a horizontal position that rests on both ends of the tester, then the batting arm on the tester is locked, then the bat arm is released so that it hits the sample until it breaks. The energy listed on the tester is read and recorded, and the impact strength is calculated (J/mm^2)

Data were analyzed using SPSS version 23 (SPSS Inc., Chicago, IL). ANOVA test was used to obtain the effect of addition chopped strand E-glass fiber and woven UHMWPE fiber analyzed the impact on the impact strength of heat-cured acrylic resin denture base material with and without thermocycling. T-independent Test to obtain the effect of thermocycling on the impact strength of heat-cured acrylic resin denture base material without reinforced fiber and addition with chopped strand E-glass fiber and woven UHMWPE fiber. LSD analysis and performed to see which fiber has the best effect to strengthen the impact strength of heat-cured acrylic resin.

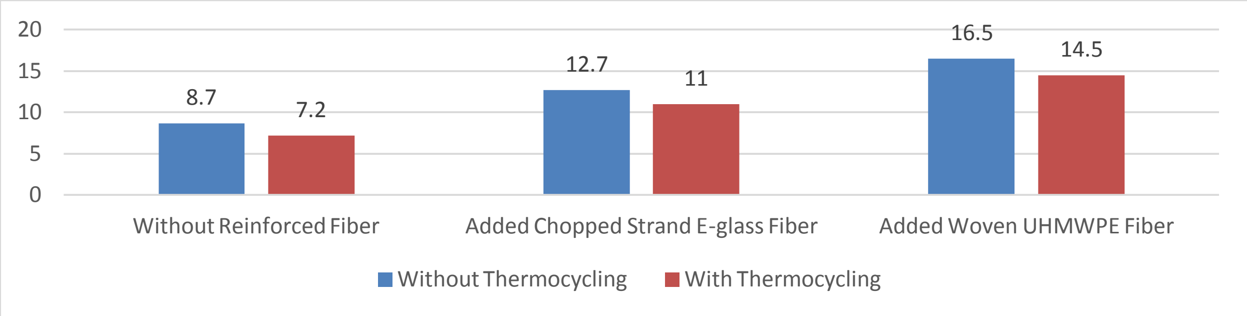
III. Result

The results showed that the average value of the impact strength in all groups without thermocycling was highest compared to the group with thermocycling. In the group without thermocycling, the mean and standard deviation values were: without fiber addition $8.7 \pm 0.7 \times 10^{-3}$ J/mm^2, with the addition of chopped strand e-glass fiber $12.7 \pm 0.4 \times 10^{-3}$ J/mm^2, and with the addition of woven UHMWPE fiber $16.5 \pm 0.5 \times 10^{-3}$ J/mm^2. Then in the thermocycling group, the mean values and standard deviations were: without the addition of fiber $7.2 \pm 0.4 \times 10^{-3}$ J/mm^2, with the addition of chopped strand e-glass fiber $11 \pm 0.5 \times 10^{-3}$ J/mm^2, and with the addition of woven UHMWPE fiber $14.5 \pm 0.6 \times 10^{-3}$ J/mm^2. (Table 1and Graphic 1)

Table 1. Impact strength value of heat-cured acrylic resin denture base material with and without the addition of glass fiber e-glass chopped strand UHMWPE woven fiber with and without thermocycling.

Group	Number of samples	Impact Strength (x 10^{-3} J/mm^2)	
		Without Thermocycling	**With Thermocycling**
Without Reinforced Fiber	1	8.07	6.7**
	2	9.15	7.37
	3	8.79	7.02
	4	9.15	6.7**
	5	9.52*	7.72*
	6	7.72**	7.72*
	Mean ± SD	**8.7 ± 0.7**	**7.2 ± 0.4**
Added Chopped Strand E-glass Fiber	1	12.21**	10.27**
	2	12.61	10.65
	3	12.61	10.65
	4	13.01	11.82*
	5	13.41*	11.04
	6	12.21**	11.43
	Mean ± SD	**12.7 ± 0.4**	**11 ± 0.5**
Added Woven UHMWPE Fiber	1	15.88**	15.47*
	2	15.88**	14.64
	3	17.15*	14.23
	4	16.3	14.23
	5	16.73	15.05
	6	17.15*	13.82**
	Mean ± SD	**16.5 ± 0.5**	**14.5 ± 0.6**

Note: * : Highest value ** : Lowest value



Graphic 1: The mean value of heat-cured acrylic resin denture base material with and without the addition of glass fiber e-glass chopped strand UHMWPE woven fiber with and without thermocycling.

Effect of E-glass and woven UHMWPE fibers addition on the impact strength of heat-cured acrylic resin denture base material without and with thermocycling

a. Without Thermocycling

The results of the One Way-ANOVA test showed that there was an effect of adding chopped strand E-glass fiber and woven UHMWPE fiber without thermocycling groups on the impact strength of heat-cure acrylic resin denture bases with p = 0,001 (p<0,05). Then the LSD test was carried out which showed that there was a significant difference between the heat-cured acrylic resin denture base material without the addition of reinforcing fiber and chopped strand E-glass fiber. Between groups of heat-cured acrylic resin denture base material with the addition of chopped strand e-glass fiber and woven UHMWPE fiber also showed a significant difference in impact strength with p = 0.001 (p<0.05). The same thing was also shown between the heat-cured acrylic resin denture base material without the addition of reinforcing material and the woven UHMWPE fiber showed a significant difference in impact strength with p = 0.001 (p<0.05). (Table 2)

Table 2. Effect of addition reinforced materials on the impact strength of heat-cured acrylic resin denture base materials without thermocycling

Group	n	Impact Strength	p
		Mean ± SD	
Without Reinforced Fiber	6	8.7 ± 0.7	0.001*
Chopped Strand E-glass Fiber	6	12.7 ± 0.4	
Woven UHMWPE Fiber	6	16.5 ± 0.5	
The difference between the impact strength mean between : – Without reinforced fiber and chopped strand E-glass fiber – Chopped strand E-glass fiber and woven UHMWPE fiber – Without reinforced fiber and woven UHMWPE fiber			0.001* 0.001* 0.001*

b. With Thermocycling

The result of One Way-ANOVA test showed that there was an effect of adding chopped strand E-glass fiber and woven UHMWPE fiber with thermocycling groups on the impact strength of heat-cure acrylic resin denture bases with p = 0,001 (p<0,05). Then the LSD test was carried out which showed that there was a significant difference between the heat-cured acrylic resin denture base material without the addition of reinforcing fiber and chopped strand E-glass fiber. Between groups of heat-cured acrylic resin denture base material with the addition of chopped strand e-glass fiber and woven UHMWPE fiber also showed a significant difference in impact strength with p = 0.001 (p<0.05). The same thing was also shown between the heat-cured acrylic resin denture base material without the addition of reinforcing material and the woven UHMWPE fiber showed a significant difference in impact strength with p = 0.001 (p<0.05). (Table 3)

Table 3. Effect of addition reinforced materials on the impact strength of heat-cured acrylic resin denture base materials with thermocycling

Group	n	Impact Strength	p
		Mean ± SD	
Without Reinforced Fiber	6	7,2 ± 0,4	0.001*
Chopped Strand E-glass Fiber	6	11 ± 0,5	
Woven UHMWPE Fiber	6	14,5 ± 0,6	

The difference between the impact strength mean between : – Without reinforced fiber and chopped strand E-glass fiber – Chopped strand E-glass fiber and woven UHMWPE fiber – Without reinforced fiber and woven UHMWPE fiber	0.001* 0.001* 0.001*

Effect of thermocycling on the impact strength of a heat-cured acrylic resin denture base with added E-glass and woven UHMWPE fibers

The results of the T-Independent Test showed that there was a thermocycling effect on the impact strength of heat-cured acrylic resin denture bases without the addition of reinforcing materials, with the addition of chopped strand e-glass fibers, and with the addition of woven UHMWPE fibers with p in all groups $p = 0.001$ ($p < 0.05$).
(Table 4)

Table 4. The value of testing the effect of thermocycling on the impact strength of heat-cure acrylic resin denture base material with and without the addition of chopped strand e-glass fiber reinforcement and woven UHMWPE fiber

Group	n	Impact Strength ($x\ 10^{-3} J/mm^2$)		p
		Without Thermocycling	With Thermocycling	
Without Reinforced Fiber	6	8.7 ± 0.7	7,2 ± 0,4	0.001*
Chopped Strand E-glass Fiber	6	12.7 ± 0.4	11 ± 0,5	
Woven UHMWPE Fiber	6	16.5 ± 0.5	14,5 ± 0,6	

IV. Discussion

Thermocycling is known as a clinical simulation method that is very close to the situation in the oral cavity. Dentures are usually in a state of hot and cold temperatures that vary according to the food being consumed. Similar to what happens when the sample is thermocycling, this process will cause changes in the form of chain elongation in the polymer structure of the heat-cured acrylic resin denture base and cause an increase in water absorption. [15,16] The water that has been absorbed will become a plasticizer and soften the denture base so that it can reduce the impact strength.[15] Thermocycling significantly reduces the mechanical strength of polymeric materials, affecting the hardness, absorption, solubility, dehydration, oxidation, and discoloration of a material.[13] The hardness of the material will increase due to the loss of ethanol, plasticizer, and the occurrence of increased water absorption after the thermocycling procedure.[12] Cheng, et al (1993) and Chow (1993) reported that water absorption will decrease in the resin matrix added with polyethylene fiber, this is because of its hydrophobic compared to resins which are hydrophilic so that they can inhibit water absorption.[18] The denture base added with glass fiber has a lower value than the denture base added with polyethylene fiber because glass fiber has rigid characteristics that can cause a decrease in the resistance of the material.

There is a significant effect of adding reinforced fibers to the heat-cured acrylic denture base on impact strength with and without thermocycling. The addition of woven UHMWPE fibers showed a significant increase in the impact strength of the denture base compared to the control group. This is because polyethylene fiber is inert and has a very high molecular weight, which makes the material stronger and has a high impact strength.[16,18] In addition, immersing polyethylene fibers into monomers can help improve adhesion to polyethylene fibers and the acrylic resin matrix by creating cracks and pits as well as a rough surface so that the material blends optimally without any gaps between the fibers.[19] According to Hadianto E, et al (2013), chemical surface treatment of polyethylene fibers (soaking using monomer) can affect the adaptation of fibers and polymers and have an impact on the ability of the fiber to increase surface energy. Penetration of monomers into the fiber will increase adhesion and reduce the possibility of gaps between the fiber and the matrix during polymerization shrinkage.[18] Good pre-impregnation will increase the mechanical strength by transferring the impact stresses from the weaker polymer matrix to the higher strength fibers.[20] The stronger the bond between the fibers and the matrix, the greater the impact strength will be. In accordance with research Lim E (2015), reports that there is a significant difference in impact strength on the PMMA denture base added with polyethylene fibers that have been surface treated because the fibers and polymers have adapted to the maximum, the load received will be distributed to the acrylic resin matrix and transmitted to the fiber, so that it can absorb greater energy than PMMA without the addition of fiber.[16,18] The addition of chopped strand e-glass fiber also showed a significant increase in impact strength on the denture base compared to the control group. This is in line with research conducted by Jaber MA (2011) which stated that there was a significant increase in impact strength in the PMMA group added with chopped strand glass fiber compared to the control group.[21]

This happens because the glass fiber has been given a silane coupling agent which acts as an adhesive material to increase the interaction between molecules in the acrylic resin so that it is more homogeneous and is also useful for improving the mechanical and physical properties of the resin, as well as for stabilizing the hydrolytic prevention of water.[8,17] In a homogeneous material, the addition of a volumetric fiber can increase the ability to distribute pressure and produce a smaller resultant force due to the absorption of more pressure on the fiber.[22] The use of chopped strands of e-glass glass fiber that has been silane will dry out the fiber, reduce water and a condensation reaction occurs between the silane and the surface. So when bonding occurs, the hydrolysis reaction can be reduced.[23,24] Similar to the research of AL-Habahbeh (2007) which stated that the addition of e-glass glass fiber into acrylic resin showed a significant decrease in water absorption because the hydrophobic fiber could anticipate the hydrophilic characteristics of acrylic resin.[23,24] Durkan RK, et al (2010) reported that the water absorption of denture base materials without the addition of fiber was higher than that given the addition of fiber because there was a possibility of a better bond so that the adhesion between the fibers and the resin matrix increased and water absorption was lower.[15]

Simulations using thermocycling for 3000 cycles (3 years) at a temperature of 5°-55°C showed that there was a significant effect in decreasing the impact strength of heat-cure acrylic resin denture bases. The thermocycling process causes the hydration process to occur similar to the clinical conditions, therefore the resin absorbs water and breaks the bond due to the presence of voids between layers.[23] Water entering the polymer material during immersion is mainly due to diffusion, and part of the polarity of the polymer chain is caused by unsaturated molecules and unbalanced intermolecular forces. The absorbed water causes the softening of the denture base, because the absorbed water can act as a plasticizer so that it can penetrate the heat-cured acrylic resin denture base polymer, this triggers the water to be able to occupy a position between the polymer chains causing the chains to separate. This causes changes in the polymer, thus allowing the chain to become unstable when subjected to loads, and this causes a decrease in impact strength.[11,18] The results show that there is a significant thermocycling effect on PMMA added with woven UHMWPE fiber on the impact strength.Lim E (2015) also reported that there was a significant thermocycling effect on the impact strength of PMMA with the addition of woven UHMWPE fiber.[18] This was due to the difficulty of adjusting the position of the woven UHMWPE fiber and the fiber used was only surface treatment by immersion using monomer so that when there was induced tension in the material, caused by changes in temperature when thermocycling can cause the formation of microcracks, and a decrease in the mechanical properties of the material. Microcracks on the material can make it easier for water to penetrate which accelerates the plasticizing process on the material.[24] A significant thermocycling effect was also shown in the PMMA group added with chopped strand e-glass fiber on the impact strength of the denture base. This can happen because during the thermocycling test, artificial saliva was used which had a detrimental effect on the polymer matrix. During the thermocycling process there was a change in temperature and humidity, temperature also affected the amount of water in the absorption due to the increased diffusion coefficient. The water that has been absorbed will react to become a plasticizer and affect the properties of the material so that at high temperatures the absorption of water will increase. Pusz A (2011) reported that the absorption of saliva on polyamide material added with e-glass glass fiber based on temperature if the higher the temperature, the faster the absorption, solubility, and hardness, and color changes occur in the polymer.[17]

V. Conclusion

The addition of chopped strand e-glass fiber and woven UHMWPE fiber showed a significant effect on the impact strength of heat-cured acrylic resin denture base with and without thermocycling. This shows that the addition of reinforcing material can reduce the occurrence of water absorption which can reduce the mechanical properties of the acrylic resin base. The simulation of the denture base with thermocycling for 3000 cycles (3 years) showed a significant decrease in the impact strength of the heat-cured acrylic resin denture base both with and without the addition of chopped strand e-glass fiber and woven UHMWPE fiber. This is caused by the position of the e-glass fiber and UHMWPE fiber which is difficult to control and the bond between the woven UHMWPE fiber is not optimal because it is only done using monomer instead of plasma treatment. The addition of chopped strand e-glass fiber and woven UHMWPE fiber can be recommended in cases where a high-impact strength base is required.

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