CODEN [USA]: IAJPBB ISSN: 2349-7750

INDO AMERICAN JOURNAL OF
PHARMACEUTICAL SCIENCES

http://doi.org/10.5281/zenodo.3350456

Available online at: http://www.iajps.com *Research Article*

A RESEARCH STUDY TO ASSESS THE USE OF SHAPE MEMORY POLYMERS IN REGULAR ORTHODONTIC PRACTICE WITH RESPECT TO ASSOCIATED FEATURES

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Article Received: May 2019 **Accepted:** June 2019 **Published:** July 2019

Abstract:

Glass fibre reinforced shape memory polymers (GFRSMPU) is a potential alternate material for the orthodontic archwires. It has added benefits over metal wires which include better mechanical features, allergy, infection and pure shape memory polymers deficiency. The process of preparation of shape memory polymer wire includes melt-spinning of polymers block copolymer for orthodontic application in two-step procedure poly (e-caprolactone) diol (PCL), 4,4^{0}-methylene bis (phenyl isocyanate) reaction and 1,4-butanediol. An orthodontic assessment was also conducted on an orthodontic model along with a metal bracket. Recovery force for shape was high (70 gf) for PU wire at a herd segment of (40 wt %) at 50^{o} C for one month. There was an exponential decrease in the first two hours in shape recovery force which reached a balanced recovery force (50 gf) in a time period of twenty days which is sufficient to recover misalignment. The shape memory PU wire is a potent new orthodontic appliance with improved and appealing esthetic appearance. We can also improve the mechanical features of GFRSMPU by adding glass fibres which will also preserve the function of shape memory. Enhanced SMPU carried better orthodontics features for the alignment at the primary stage along with other medical aspects.

Keywords: *Orthodontic, Misalignment, Teeth, Infection, Allergy, Glass Fiber, Material, Metal, Arch Wires, Shape Memory, Ceramics and Polymer.*

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Please cite this article in press Amra Minhas Abid et al., ***A Research Study to Assess the Use of Shape Memory Polymers in Regular Orthodontic Practice With respect To Associated Features.,*** *Indo Am. J. P. Sci, 2019; 06(07).*

INTRODUCTION:

The advantages of shape memory alloys are rapid recovery within one second only, two-way reversible memory potential training and an apparent superelasticity at lower temperatures due within the austenite phase. Contrary to that the polymers exhibit an intrinsic effect of the shape memory which is taken from highly coiled constituent chains (mechanically extendable); this energy is also storable when cooled down below the temperature of glass transition, melting point, amorphous polymer, semicrystalline or crystalline polymer. After fixing to a certain shape the mechanical output can be obtained from the polymeric sample and it can restore a stress-free state after the heating process at a critical temperature or regaining of coiled entropy of frozen chains. SMPs are more beneficial than SMAs in terms of recovering deformities, temperatures transitions and low-cost processing. Orthodontics involves corrective appliances application such as braces which move the teeth. A brace comprises of orthodontic archwire and bracket. Normally nickel-titanium alloy and stainless steel are used because of their suitable features such as operability, durability, fatigue, flexibility and rigidity [1].

Aesthetic issues are due to the metallic colour which has been improved through transparent materials, tooth-coloured material or translucent [2 – 4]. Thermoplastic BSMP features exceeding glass temperature whose elasticity and rubber modulus are distributed from physical cross-links. Memory polymer shape consists of blended crystalline polymer which is selected from polyglycolide, poly (vinylidene fluoride), copolymers, polylactide, poly (hydroxybutyrate), polyethylene, p poly (ethylene glycol), poly (vinyl chloride), polyethylene-co-vinyl acetate, copolymers of polyvinylidene chloride, poly (vinylidene chloride) and polyvinyl chloride along with an amorphous polymer which is selected from polymethyl acrylate, poly (vinyl acetate), atactic polymethyl methacrylate, poly ethyl acrylate, syndiotactic poly methyl methacrylate and isotactic polymethyl methacrylate.

Newman did a study a pioneered a clear polymer bracket with the help of polycarbonate in order to almost invisible (labial appliance) back in the 1960s [5]. In orthodontic treatment, it easily fractures with applied force [6]. Recently, an alternative aesthetically better orthodontic material has also evolved with better features such as stainless-steel wire (Teflon-coated) or polycarbonate brackets (fibrereinforced) [7 – 11]. In the variety of SMPs, increasing attention has been paid to shape memory polymers (PU) which are composed of soft segments and hard segments; the researchers are interested in it because of its biomedical application, industrial application and scientific interest [12 – 16]. PU consists of phase separated hard and soft segment structures because of its thermo-dynamic immiscibility. Physical crosslinks are provided through hard segments and reversible phase transformation is provided by soft segments which provide the required effect of shape memory. We can control the PU transition temperature by glass transition temperature as it is close to body temperature. Therefore, we can achieve PU recovery for the misaligned teeth through body temperature thermal heating. Other embodiment of shaping an orthodontic appliance includes shape memory polymer by injection moulding, profile extrusion, casting, die cutting, compression moulding, dipcoating, rotational moulding, blow-moulding, solid freeform fabrication, rapid prototyping or various combinations. Sample preparation is explained in Figure – I. We dried (MDI, Junsei Chemical), 4,40Methylene bis (phenyl isocyanate) and poly (e-caprolactone) diol (PCL) (MW=3000 g/mol) before use in a vacuum oven and stored 1,4butanediol (BD, Duksan Chemical) in molecular sieve (4 A˚). Twostep process as shown in the Figure – I shows PU synthesis.

shape memory polyurethane used in this study

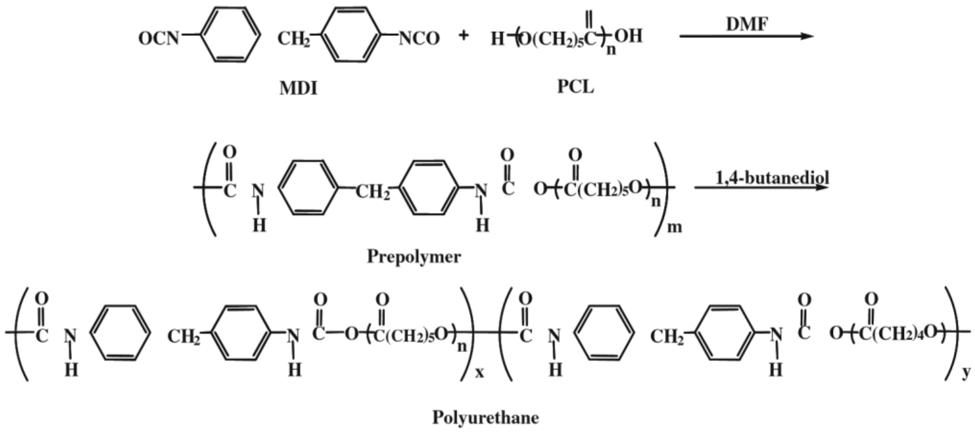
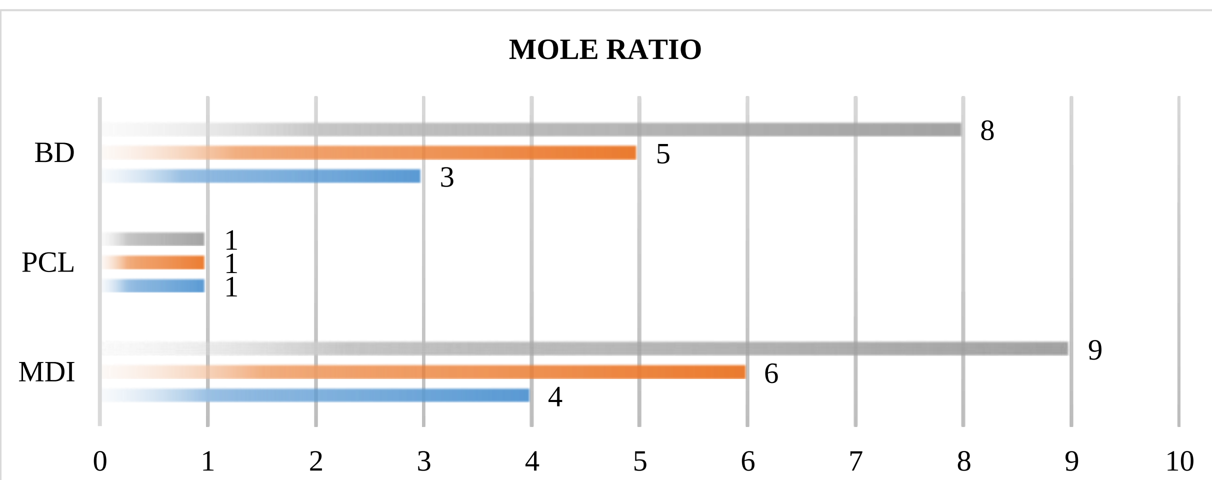


Figure – I: Synthetic Procedure

Detailed thermal shape memory PU features and Compounding formulations are given in Table – I for the sample preparation.

Table – I: Thermal shape memory PU features and Compounding formulations

Mole Ratio			**HS Content (Wt %)**	**M aw (g/mol)**	**T eb (C)**	**DH cm (J/g)**	**T dd (C)**
MDI	**PCL**	**BD**					
4	1	3	30	28096	36.6	7.6	287
6	1	5	40	31159	39.5	13.2	301
9	1	8	50	39547	43.5	13.1	313



An additional drying was also carried out for 24 hours at a temperature of 60ºC. Orthodontic PU wire was prepared by synthesized PU with the help of twin screw extruder. We set the moulding temperature in the bracket of (150ºC – 210ºC) with an average melt-spun PU wire diameter of (0.387) mm. Before the measurement of shape recovery force, we elongated the samples at a temperature of 60ºC for 1005 elongation and after that, we cool it to room temperature. Each sample was measured for shape recovery force at a constant temperature of 50ºC. Test temperature was also the same. We also observed the behaviour of shape memory through sample folded in the form of a ring at a temperature of 60ºC in icy cold water [17].

The orthodontic appliance fabrication process is described in detail as under. The thickness of orthodontic appliance wire was (0.387) mm and its length was (150) mm. Its elongation was carried out at 60ºC and cooled down to room temperature. Length of the wire was according to the requirement of misaligned teeth. This research used a Japanese reference dental model for orthodontic treatment. Before the commencement of orthodontic treatment, the separation process between teeth was carried out and prepared the surface of the tooth with unfilled resin primer and filling composite on the bracket. We firmly placed the bracket onto the middle of the buccal crown surface and also corrected its orientation. Excessive cement and composite were removed.

RESULTS AND DISCUSSION:

DSC measurements were determined through temperature transition. Figure – II shows the scanned DSC thermograms. The endothermic peaks are available near the temperature of (36ºC – 42ºC) are because of the PCL crystals melting temperature in PU segment domain which acts as the shape memory temperature transition. Increased hard segment content also yield increased temperature because of the formation of the perfect crystals which causes the separation of soft and hard segment. Table – I also shows measurements of thermogram in the hard segment. The endothermic peak is achieved near 200ºC is because of hard segment melting which also enlarges the peak. Phase-separated hard segment may also lead to the formation of necessary physical crosslinks for the achievement of sample shape recovery [12]. Table – II reflects mechanical PU properties.

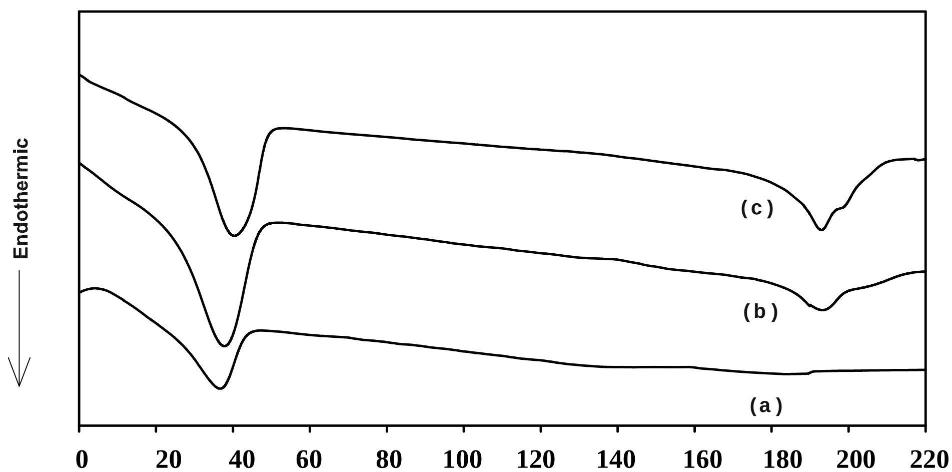


Figure – II: DSC Heating Scans

Various hard segment contents were observed in the DSC heating scans as reflected in the Figure with an increase in the PU. The hard segment increase was up to forty percent which increased the hard domain and also increased the intermolecular hard segment hydrogen bonding. We also obtained a tensile strength from 17.8 MPa to 26.8 MPa for 30% to 50% hard segment content; whereas, at fifty percent the breaking strength was at its peak.

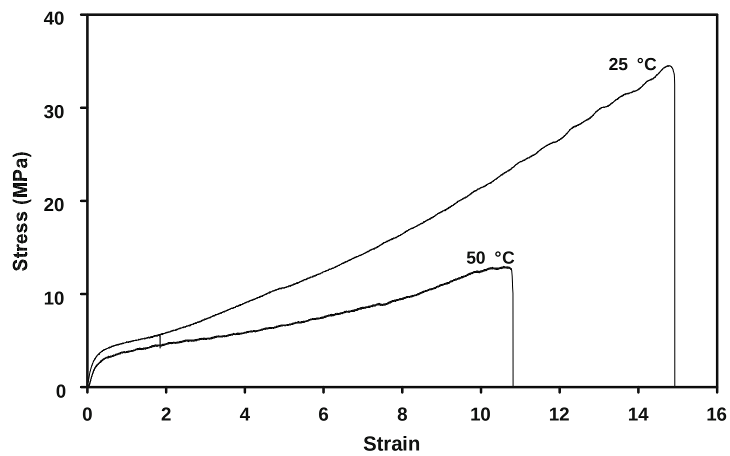
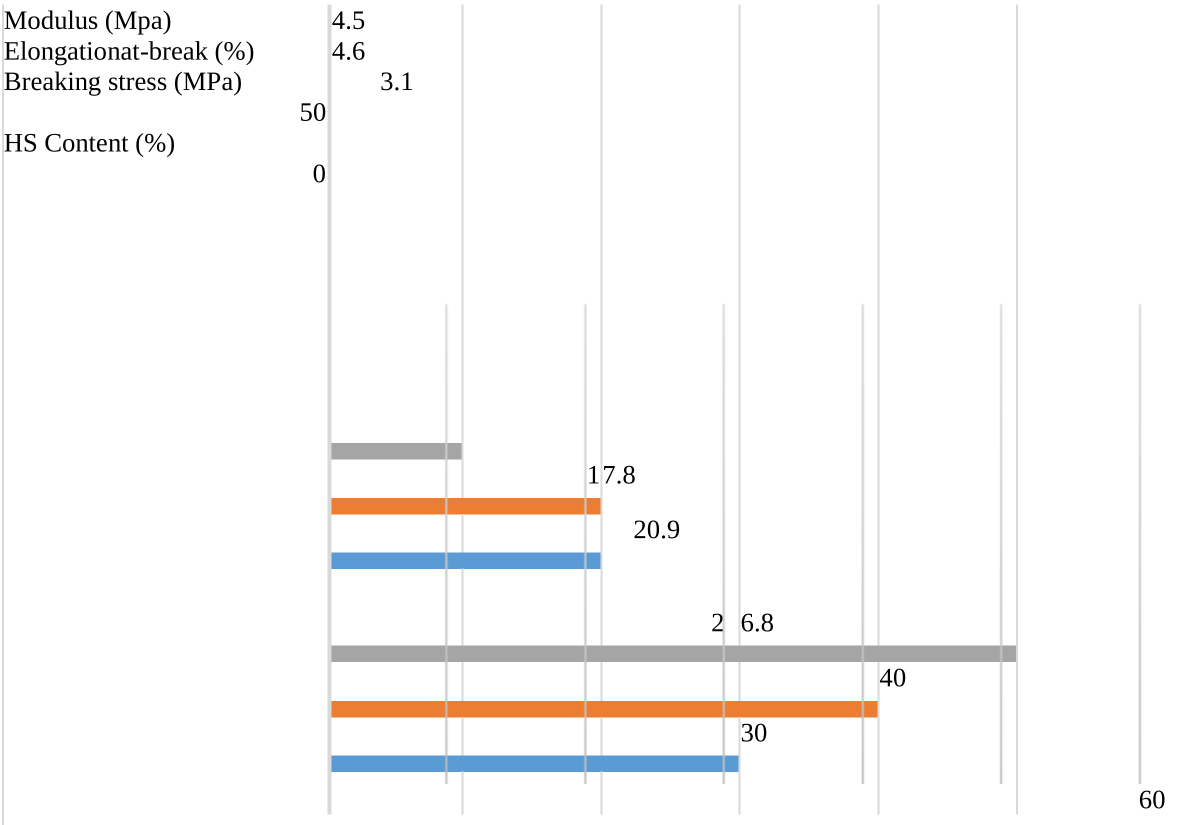


Figure – III: Stress-Strain Curves

Stretching may stop at a higher hard segment of the PU sample rigidity and reduced physical crosslinking degree at the low hard segment content may attribute in the reduced elongation breaking of the PU.

Table – II: Tensile properties of shape memory PU

HS Content (%)	Breaking stress (MPa)	Elongation at break (%)	Modulus (Mpa)
30	20.9	1.484	3.1
40	26.8	1.215	4.6
50	17.8	1.161	4.5



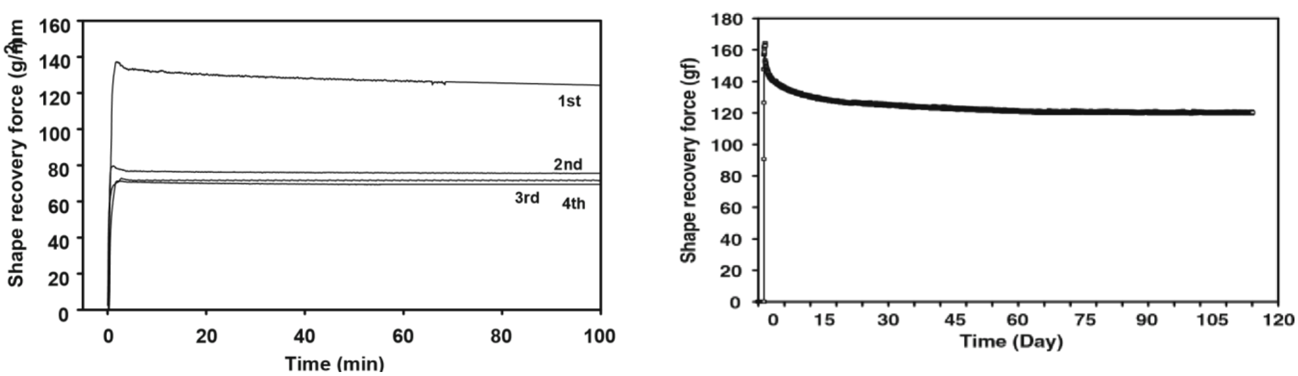
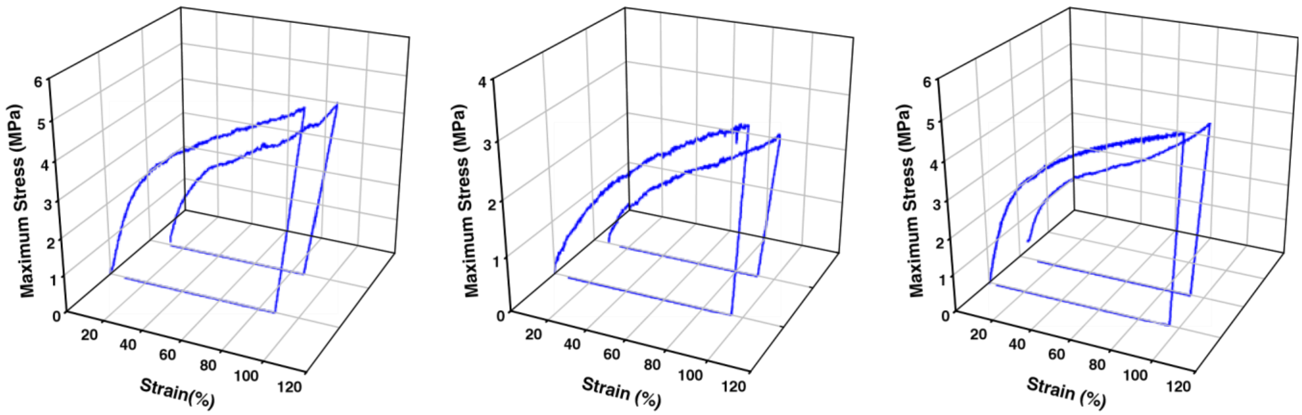


Figure – IV: Shape Recovery

Mechanical properties are temperature dependent which is not the same for the shape memory metals. Stress-Strain curves are presented in Figure – III. 50ºC sample presents reduced values of the stress in comparison with 25ºC. Still, 50ºC is suitable for the support of the teeth in the course of orthodontic treatment. Samples also underwent a shape memory assessment and thermo-mechanical behaviour assessment. Most of the PUs managed to retain better shape on the content of the hard segment. Increased hard segment content increases the recovery rate. Full recovery of the original shape is possible at a temperature more than the melting point of PU wire for PCL crystals. After application of stress on the PU wire the soft segment extends in the direction of stress instead of the hard segment as the glass state is near hard segment; whereas, the soft segment is rubbery beyond the limit of transition limit of temperature. Hard segment stabilization is responsible for the recovery above the limit of the transition temperature. PU samples in hard segment present better shape memory function recovery from thirty to fifty wt% which is also inconsistent with PU wire shape recovery.



30 wt% 40 wt% 50 wt%

Figure – V: Thermomechanical properties at different levels of Stress and Strain

The temperature for shape recovery assessment is normal body temperature but the higher temperature of 50ºC was selected as SMP wire requires longer duration at body temperature. The outcomes of the test at 50ºC are also acceptable to assess the SMP wire behaviour as we assessed the recovery in terms of time and temperature. There was a sharp increase in the recovery force (135 gf) on a temperature of 50ºC. No further increase was observed beyond 50ºC and with the passage of time, the force of sharp recovery also reduced. Sharp recovery force reduced to (125 gf) after sixty minutes. Sharp recovery force was high in the first cycle and it reduced as the test cycles increased. A particular decrease was visible in the second cycle and value became balanced in the final cycles. Reduced value is an outcome of molecular state incomplete recovery in both soft and hard segments after the previous cycle. Most of the materials present similar fatigue phenomena in their mechanical features. Even after three months, the samples preserve a recovery force of (120 gf). Furthermore, the shape recovery curve shows constant value with respect to time after two months; which speaks for the better shape recovery features of SMPU in orthodontic treatment for three months and longer durations.

The orthodontic behaviour was also studied for shape memory PU wire through a dental model. In this model, we used melt-spinning prepared PU wire which was connected to multiple brackets. Before its connection with teeth, the appliance was elongated 1.5 times more than its actual size at a temperature of 65ºC in order to achieve thermal stability. We did not use attaching bracket rather we used rubber ring to attach the appliance with the surface of the teeth. It is normally applied with a metal alloy appliance. Shape memory PU wire gives a more appealing aesthetic look in comparison to the bracketequipped appliance because of the transparency of the PU sample. The ceramic bracket can further improve the overall aesthetic look of the appliance.

Figure – VI: Different Photographs of appliances before orthodontic treatment and after orthodontic treatment for misaligned teeth treatment

PU wire was used for the orthodontic assessment. Teeth moved clearly at the desired level after heating the appliance at about 40ºC (above transition temperature). While orthodontic appliance was heating the measuring, the chamber was maintained for 50ºC constant temperature. At an initial stage, the misaligned teeth started moving towards wire-type appliance slowly because of the shape recovery within the brackets. Misaligned teeth almost adjusted in one hour to the desired level. This movement was too rapid for orthodontic treatment. However, it is important to note that displacement and recovery force is controllable by adjusting predetermined retention of the shape on the base of elongation magnitude of wire with respect to initial prepared size. Total achieved teeth displacement was 8.5 mm in one hour. It represents that predetermined appliance shape retention can PU wire shape recovery upon heating. Figure – VI represents the orthodontic treatment before and after applications. We can adjust the misaligned teeth to a required position in the state where tooth movement degree is depending on relative teeth position. Subsequently, shape memory PU wire is a strong orthodontic application; whereas, it also provides an appealing aesthetic appearance.

CONCLUSIONS:

With the help of shape memory PU wire as a potential orthodontic appliance, the alignment of teeth is possible through orthodontic treatment. Our prepared PU wire provides higher retention of the shape with 85% recovery rate with better mechanical features with 26.8 MPa breaking stress at a hard segment (40 wt%). Shape recovery force of wire is suitable to align the misaligned teeth in the orthodontic treatment at the transition temperature. PU wire is potential and promising material which has different appropriate aesthetic features and new orthodontic appliances.

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