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Braided Composite Configurations for Dental Applications

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Abstract:
Braiding technology has been introduced to the composites industry in a spectrum of applications. Braiding configuration is defined by monitoring its variables according to the intended final usage which is the dental fiber posts in this study. Fiber post is a small rod used to support the teeth that have short clinical crown in the definitive restoration. Fiber posts are accepted widely because of their enhanced aesthetic and mechanical properties which enrich the dental field.
Braided composite's manufacturing process used to be achieved by passing the braided perform through the resin emulations, but in this paper a novel procedure is followed to fabricate the posts through two consecutive processes; first is the braiding process while the second is the melting process. Three different thermoplastic types; Polypropylene (PP), Polyester (PET), and Polyamide (PA) have been braided with the glass-fibers (GF), then the thermoplastic part of the braided perform has been melted to achieve the composite posts.
The posts were assessed visually and mechanically, PP posts show the best performance visually and mechanically while PET posts show the least values in the mechanical testing and the most brittle forms in the visual assessment. Moreover, the PA posts show better mechanical values than the PET, but and the least homogenous forms in the visual assessment. The PET and PA posts brittleness could be attributed to the fabrication method used in this current approach which could have caused an accumulation of humidity because of less applied pressure on the mold during the melting process.

Keywords:
Braiding technology, emulation, configuration, resin bath, composite, thermoplastic, dental posts, flexural modulus.

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1- Introduction:
Braiding process is the interlacing act between three or more yarns diagonally to the axis of the product. This axis is the longest dimension of the produced perform (braid)[1]. Braids could be linear, curved, plane shell, or solid structures which could be one, two, or three dimensions. Moreover, one of the most important factors of the braiding process is the braiding angle which could be a constant braiding angle or a variable one[2].
Braiding angle is the angle which results from the diagonal interlacing between the braided yarns and the braid's axis, this angle can produce compact or open braids according to its acuteness[2]. Moreover, this angle is controlling the resulted braid weather its graded (compact or closed in places and open in others) or constant according to the angle itself whether it's a variable or a constant one respectively[3]. By monitoring the manufacturing process and its different parameters, any shape of the braids could be obtained with regard to their end usages[3].
Braiding technology has been used in the composite industry because of the distinguishing properties such as flexibility of forming different shapes including complex and very fine composite materials and products[1]. Braiding process also could participate in reducing the cost of the composite manufacturing process, as well as controlling the fiber orientation in the composite form through controlling the braiding angle, yarns count, number of used braiding spindles (yarns), and many other factors[2,3].
Braiding technology has been used in many reinforced composites' applications such as pipes, constructions, dental materials and many other applications[4]. This paper is focusing on using braiding technology with different parameters in fabricating dental fiber posts.
These posts are used in the endodontically treated

teeth[5,6], dental fiber posts have been widely used in the past decades due its superior advantages such as aesthetic appearance, moderate flexural strength which is similar to the teeth's dentine, easier in implanting and removing posts (if needed), and many other advantages[7,8].
Fiber reinforced composite posts used to be fabricated using the traditional method of fibers infusion through the resin emulation[9,10]. In this paper a novel method of manufacturing has been attempted which involves melting the thermoplastic yarns in the braided perform to act like the composite's resin while keeping the reinforcement yarns (fibers) oriented as per their initial position in the braided perform and consequently in the resulted composite post.

2- 2- Materials and methods:

The experimental plan includes information about the different used materials and the adopted work methods.

2.1. Materials:

The materials used in the research project are divided into two main categories:
1- Reinforcement fibers
2- Thermoplastic fibers (matrix)

2.1.1. Reinforcement Fibers:

The reinforcement fibers used in this research were fiberglass yarns.

- Fiberglass yarns were generously donated by AGY industries, located in the U.S.
- Fiberglass yarns were divided into two main categories according their silane:
- First category was E-glass fiber treated with starch (ECE225) with a count of "22 Tex"
- Second category was consisting mainly of two types of glass fiber with a specialized silane for coupling with thermoplastic fibers under a commercial name of "561 sizing" as follows:

E-glass type (ECDE75) with a count of "66 Tex"
S-glass type (SCG75) with a count of "68 Tex".
Different yarn specifications are listed in Tables 1, 2, and 3[11].

Table 1 E-glass-fiber specifications

Product	ECE225
Glass Type	E
Filament Diameter – microns	7
Binder	622
Bobbin	8542
Plies	1/0
Nominal Yield - yd/lb	22,500
Tex - g/1000 m	22
Tex tolerance +/	1.2
Nominal Solids %	1.4
Solids Tolerance +/-	0.25
Nominal Twist TPI (TPM)	0.5Z (Z20)
Twist Tolerance +/- TPI (TPM)	0.15 (6)
Max. Broken Filaments	10
Minimum Tensile - lb (N)	2.4 (10.7)
Average Bare Glass Tensile - lb (N)	3.48QW (15.5)
Approximate Yarn Diameter - in (mm)	0.0065 (0.165)

Table 2 S-glass-fiber with silane specifications

Product	SCG75
Glass Type	S – 2 GLASS
Filament Diameter – microns	9
Binder	561
Bobbin	7636
Plies	1/0
Nominal Yield - yd/lb	7295
Tex - g/1000 m	68
Tex tolerance +/	6.2
Nominal Solids %	1.17
Solids Tolerance +/-	0.26
Nominal Twist TPI (TPM)	1.0Z (Z40)
Twist Tolerance +/- TPI (TPM)	0.3 (12)

Max. Broken Filaments	9
Minimum Tensile - lb (N)	7.1 (31.6)
Average Bare Glass Tensile - lb (N)	10.8 (48)
Approximate Yarn Diameter - in (mm)	0.0076 (0.192)

Table 3 E-glass-fiber with silane specifications

Product	ECDE75
Glass Type	E
Filament Diameter – microns	6
Binder	561
Bobbin	8571
Plies	1/0
Nominal Yield - yd/lb	7500
Tex - g/1000 m	66.1
Tex tolerance +/	4.3
Nominal Solids %	1.42
Solids Tolerance +/-	0.17
Nominal Twist TPI (TPM)	0.7Z (Z28)
Twist Tolerance +/- TPI (TPM)	0.21 (8)
Max. Broken Filaments*	10
Minimum Tensile - lb (N)	5.7(25.4)
Average Bare Glass Tensile - lb (N)	9.6 (43)
Approximate Yarn Diameter - in (mm)	0.106 (0.269)

2.1.2. Thermoplastic Fibers: Fiber reinforced composites used to be fabricated using a resin of thermoset emulsions with the reinforcement fibers in a conventional method of forming composite materials[10,12–14]. In the novel suggested method, resin (matrix) is being used in a form of thermoplastic yarns to take advantage of their low melting points, ease of formation and low prices compared to thermosets.

Three different types of thermoplastic yarns were used; the count was constant for the three types which is 300 Denier whether plied or single yarns. The first type was polyester (PET), second one was Polypropylene (PP) and the third one was polyamide (Nylon 6, PA). The technical specs and physical properties of each thermoplastic yarn type are listed in table 4[11].

Table 4 Thermoplastic yarns' specifications

Yarns type	**Polyester (PET)**	**Polypropylene (PP)**	**Polyamide (PA)**
Count	300 denier	300 denier	300 denier
Melting point	295°C	180°C	265°C
Approximate Yarn Diameter - in (mm)	0.0045 (0.135)	0.0045 (0.135)	0.0045 (0.135)

All of the used thermoplastic yarn in the different braids act as a homogeneous and well distributed matrix after the melting stage.

1.2. Methods: Experimental design has been carried out on four consecutive stages by using different materials and different configurations of the used braiding machine (figure 1):

2.2.1. first stage (A): defining the most suitable braiding angle: Different gears were used (tension and speed) to make different braided perform, after many trials it has been shown that the best braiding angle is obtained by using the two gears of 42 teeth's gear meshing with the 20 teeth's gear so that we could transmit higher torque and consequently obtain the tightest structure, the most acute and closed angle, and the least radius for the produced braids. Having this result was the first step to start the executive plan after clarifying an initial and basic parameter of the whole braiding process.

Figure 1 Braiding machine

For the first stage settings shown in table 5 have been followed on the braiding machine to produce the very early samples that defines the difference between the different braiding angles using different speed gears (20-30-40) teeth meshing with a constant tension gear of 42 teeth. These settings were used with braids that have a core and also those that possess no core.

Table 5 stage one braiding process' configurations

No	Thermoplastic Material Type	Thermoplastic Material Count/Denier	Number of working spindles	Core Type	Core Count/Denier	Braiding angle gear teeth	Notes
1	Polyester	150	48	None	0	20	No reinforcement fibers used - tension angle is constant of 42 teeth
2	Polyester	150	48	None	0	30	
3	Polyester	150	48	None	0	40	
4	Polyester	150	48	Polyester	16800	20	
5	Polyester	150	48	Polyester	16800	30	
6	Polyester	150	48	Polyester	16800	40	

- **2.2.3 The second stage (B): was defining a suitable number of working spindles in the braiding machine:** which was 14 spindles ±1 according the needed ratio between the reinforcement yarns to the thermoplastic ones to obtain a small braid radius as needed for the fiber posts, GF was chosen to be the reinforcement yarns representative. GF yarns were distributed with the three different thermoplastic yarns (PET – PP- PA) on the braiding machine spindles as per the needed ratio per each.
- Five different braids with five different ratios for each Thermoplastic matrices were executed (fifteen in total for the three thermoplastic types) each sample has been performed with three different cores, thus 45 samples were produced in this stage.
- Tables 6, 7, and 8 represent the operating variables used while producing the second stage samples. Then, the number of the working spindles have been reduced to obtain less diameter of the produced braids and consequently the fiber posts, different ratios (fiber volume fraction) have also been tried to find out the effect of increasing the fibers total amount on the resulted braids and consequently posts. Also GF has been chosen to be fixed representative for the reinforcement fibers to achieve the translucency property. Three different thermoplastic types (PET –PP –PA) have been used separately with the same settings as in the below three tables in order to find out the best performance between them as a matrix and the fiberglass as a reinforcement in the resulted fiber post:

Table 6 stage two braiding process' configurations (PET)

Sample Code	PET:GF Spindles	PET :GF Count	Mixed Spindles	Mixed Counts	PET:GF Percentage	Total spindles	Total counts	Core
S1/GF	12 : 3	300 :400 (2*150): (2*200)	0	0	75% : 25%	15	4800	**6 GF yarns each 2800 = 16800 Denier /GF**
S2/GF	8 : 4	300 :400	1	300 PET -200 GF	60% :40%	13	4500	
S3/GF	8 : 6	300 :400	0	0	50% : 50%	14	4800	
S4/GF	6 :7	300 :400	0	0	40% :60%	13	4600	
S5/GF	4 : 9	300 :400	0	0	25% : 75%	13	4800	
S1/PET	12 : 3	300 :400	0	0	75% : 25%	15	4800	**Two yarns of PET each 8400 = 16800 Denier/PET**
S2/PET	8 : 4	300 :400	1	300 PET -200 GF	60% :40%	13	4500	
S3/PET	8 : 6	300 :400	0	0	50% : 50%	14	4800	
S4/PET	6 : 7	300 :400	0	0	40% :60%	13	4600	
S5/PET	4 : 9	300 :400	0	0	25% : 75%	13	4800	
S1/MIX	12 : 3	300 :400	0	0	75% : 25%	15	4800	**3 GF yarns each 2800 = 8400 Denier + one single yarn of PET 8400 Denier, Total 16800 denier/mix**
S2/MIX	8 : 4	300 :400	1	300 PET -200 GF	60% :40%	13	4500	
S3/MIX	8 : 6	300 :400	0	0	50% : 50%	14	4800	
S4/MIX	6 : 7	300 :400	0	0	40% :60%	13	4600	
S5/MIX	4 : 9	300 :400	0	0	25% : 75%	13	4800	

Table 7 stage two braiding process' configurations (PP)

Sample Code	PP: GF Spindles	PP: GF Count	Mixed Spindles	Mixed Counts	PP:GF %	total spindles	total counts	Core
SS1/GF	12 : 3	300 :400 300: (2*200)	0	0	75%:25 %	15	4800	**6 GF yarns each 2800 = 16800 Denier/GF**
SS2/GF	8 : 4	300 :400	1	300 PP-200 GF	60%:40 %	13	4500	
SS3/GF	8 : 6	300 :400	0	0	50%:50 %	14	4800	
SS4/GF	6 :7	300 :400	0	0	40%:60 %	13	4600	
SS5/GF	4 : 9	300 :400	0	0	25%:75 %	13	4800	
SS1/PP	12 : 3	300 :400	0	0	75%:25 %	15	4800	**7*2400 PP = 16800 Denier/PP**
SS2/PP	8 : 4	300 :400	1	300 PP-200 GF	60%:40 %	13	4500	
SS3/PP	8 : 6	300 :400	0	0	50%:50 %	14	4800	
SS4/PP	6 : 7	300 :400	0	0	40%:60 %	13	4600	
SS5/PP	4 : 9	300 :400	0	0	25%:75 %	13	4800	

SS1/MIX	12 : 3	300 :400	0	0	75%:25 %	15	4800	**3 GF yarns each 2800 = 8400 Denier ,+ (3*2400) PP+ 1200 PP = 8400 PP , TOTAL= 16800 Denier/MIX**
SS2/MIX	8 : 4	300 :400	1	300 PP- 200 GF	60%:40 %	13	4500	
SS3/MIX	8 : 6	300 :400	0	0	50%:50 %	14	4800	
SS4/MIX	6 : 7	300 :400	0	0	40%:60 %	13	4600	
SS5/MIX	4 : 9	300 :400	0	0	25%:75 %	13	4800	

Stage 4 table PP

Table 8 stage two braiding process' configurations (PA)

Sample Code	**PA: GF Spindles**	**PA: GF Count**	**Mixed Spindles**	**Mixed Counts**	**PA:GF Percentage**	**Total spindles**	**Total counts**	**Core**
SSS1/GF	12 : 3	300: 400 (4*75): (200*2)	0	0	75% : 25%	15	4800	**6 GF yarns each 2800 = 16800 Denier /GF**
SSS2/GF	8 : 4	300:400	1	300 PA - 200 GF	60% :40%	13	4500	
SSS3/GF	8 : 6	300:400	0	0	50% : 50%	14	4800	
SSS4/GF	6 :7	300:400	0	0	40% :60%	13	4600	
SSS5/GF	4 : 9	300:400	0	0	25% : 75%	13	4800	
SSS1/PA	12 : 3	300:400	0	0	75% : 25%	15	4800	**(1900*8) + (280*6) = 16800 Denier/PA**
SSS2/PA	8 : 4	300:400	1	300 PA - 200 GF	60% :40%	13	4500	
SSS3/PA	8 : 6	300:400	0	0	50% : 50%	14	4800	
SSS4/PA	6 : 7	300:400	0	0	40% :60%	13	4600	
SSS5/PA	4 : 9	300:400	0	0	25% : 75%	13	4800	
SSS1/MIX	12 : 3	300:400	0	0	75% : 25%	15	4800	**3 GF yarns each 2800 = 8400 Denier + (1900*4)PA+ (280*3) PA= 16800 MIX**
SSS2/MIX	8 : 4	300:400	1	300 PA - 200 GF	60% :40%	13	4500	
SSS3/MIX	8 : 6	300:400	0	0	50% : 50%	14	4800	
SSS4/MIX	6 : 7	300:400	0	0	40% :60%	13	4600	
SSS5/MIX	4 : 9	300:400	0	0	25% : 75%	13	4800	

Stage 4 table PA

2.2.3. The third stage(C): was covering all of the produced samples in stage two with a thermoplastic sheath; Same samples that have been obtained in the second stage with the three different thermoplastics, have been reproduced then used as a core to a fully thermoplastic sheath using the same type of the thermoplastic which have been used in the initial sample before acting as a core by using sixteen spindles of a thermoplastic yarns to make the sheath and the sheath type is defined according to the used thermoplastic yarns in the initial braid (ex; covering the PET & GF samples with a pure PET sheath) in order to increase the penetration of thermoplastic matrix though the whole fiber post after melting and also to support the outer layer of the resulting post.

Tables 9, 10, and 11 represent the operating variables used while producing the third stage samples.

Table 9 stage three braiding process' configurations (PET)

Sample Code	CORE 2				Covering Sheath	PET : GF Percentage	Total spindles	Total counts	Core 1
	PET: GF Spindles	PET: GF Count	Mixed Spindles	Mixed Counts					
S1/GF	12 : 3	300 :400 (2*150): (2*200)	0	0	**16 spindle PP , each count is 300 denier**	87.5% : 12.5%	31	9600	**6 GF yarns each 2800 = 16800 Denier /GF**
S2/GF	8 : 4	300 :400	1	300PET -200 GF		82% :18%	29	9300	
S3/GF	8 : 6	300 :400	0	0		50% : 25%	30	9600	
S4/GF	6 :7	300 :400	0	0		70% :30%	29	9400	
S5/GF	4 : 9	300 :400	0	0		62.5% : 37.5%	29	9600	
S1/PP	12 : 3	300 :400	0	0	**16 spindle PP , each count is 300 denier**	87.5% : 12.5%	31	9600	**Two yarns of PET each 8400 = 16800 Denier/PE T**
SS2/PP	8 : 4	300 :400	1	300PET -200 GF		82% :18%	29	9300	
S3/PP	8 : 6	300 :400	0	0		50% : 25%	30	9600	
S4/PP	6 : 7	300 :400	0	0		70% :30%	29	9400	
S5/PP	4 : 9	300 :400	0	0		62.5% : 37.5%	29	9600	
S1/MIX	12 : 3	300 :400	0	0	**16 spindle PP , each count is 300 denier**	87.5% : 12.5%	31	9600	**3 GF yarns each 2800 = 8400 Denier + one single yarn of PET 8400 Denier, Total 16800 denier/mix**
S2/MIX	8 : 4	300 :400	1	300PET -200 GF		82% :18%	29	9300	
S3/MIX	8 : 6	300 :400	0	0		50% : 25%	30	9600	
S4/MIX	6 : 7	300 :400	0	0		70% :30%	29	9400	
S5/MIX	4 : 9	300 :400	0	0		62.5% : 37.5%	29	9600	

Table 10 stage three braiding process' configurations (PP)

Sample Code	CORE 2				Covering Sheath	PP : GF Percentage	Total spindles	Total counts	Core 1
	PP: GF Spindles	PP: GF Count	Mixed Spindles	Mixed Counts					
SS1/GF	12 : 3	300 :400 300: (2*200)	0	0	**16 spindle PP , each count is 300 denier**	87.5% : 12.5%	31	9600	**6 GF yarns each 2800 = 16800 Denier/GF**
SS2/GF	8 : 4	300 :400	1	300PP-200 GF		82% :18%	29	9300	
SS3/GF	8 : 6	300 :400	0	0		50% : 25%	30	9600	

SS4/GF	6 :7	300 :400	0	0		70% :30%	29	9400	
SS5/GF	4 : 9	300 :400	0	0		62.5% : 37.5%	29	9600	
SS1/PP	12 : 3	300 :400	0	0	**16 spindle PP , each count is 300 denier**	87.5% : 12.5%	31	9600	**7*2400 PP = 16800 Denier/PP**
SS2/PP	8 : 4	300 :400	1	300PP-200 GF		82% :18%	29	9300	
SS3/PP	8 : 6	300 :400	0	0		50% : 25%	30	9600	
SS4/PP	6 : 7	300 :400	0	0		70% :30%	29	9400	
SS5/PP	4 : 9	300 :400	0	0		62.5% : 37.5%	29	9600	
SS1/MIX	12 : 3	300 :400	0	0	**16 spindle PP , each count is 300 denier**	87.5% : 12.5%	31	9600	**3 GF yarns each 2800 = 8400 Denier ,+ (3*2400) PP+ 1200 PP = 8400 PP , TOTAL= 16800 Denier/MIX**
SS2/MIX	8 : 4	300 :400	1	300PP-200 GF		82% :18%	29	9300	
SS3/MIX	8 : 6	300 :400	0	0		50% : 25%	30	9600	
SS4/MIX	6 : 7	300 :400	0	0		70% :30%	29	9400	
SS5/MIX	4 : 9	300 :400	0	0		62.5% : 37.5%	29	9600	

Table 11 stage three braiding process' configurations (PA)

Sample Code	**CORE 2**				**Covering Sheath**	**PA : GF Percentage**	**Total spindles**	**Total counts**	**Core 1**
	PA: GF Spindles	**PA: GF Count**	**Mixed Spindles**	**Mixed Counts**					
SSS1/GF	12 : 3	300: 400 (4*75): (200*2)	0	0	**16 spindle PA , each count is 300 denier**	87.5% : 12.5%	31	9600	**6 GF yarns each 2800 = 16800 Denier /GF**
SSS2/GF	8 : 4	300:400	1	300 PA - 200 GF		82% :18%	29	9300	
SSS3/GF	8 : 6	300:400	0	0		50% : 25%	30	9600	
SSS4/GF	6 :7	300:400	0	0		70% :30%	29	9400	
SSS5/GF	4 : 9	300:400	0	0		62.5% : 37.5%	29	9600	
SSS1/PA	12 : 3	300:400	0	0	**16 spindle PA , each count is 300 denier**	87.5% : 12.5%	31	9600	**(1900*8) + (280*6) = 16800 Denier/PA**
SSS2/PA	8 : 4	300:400	1	300 PA - 200 GF		82% :18%	29	9300	
SSS3/PA	8 : 6	300:400	0	0		50% : 25%	30	9600	

SSS4/PA	6 : 7	300:400	0	0		70% :30%	29	9400	
SSS5/PA	4 : 9	300:400	0	0		62.5% : 37.5%	29	9600	
SSS1/MIX	12 : 3	300:400	0	0	**16 spindle PA , each count is 300 denier**	87.5% : 12.5%	31	9600	**3 GF yarns each 2800 = 8400 Denier + (1900*4)PA+ (280*3) PA= 16800 MIX**
SSS2/MIX	8 : 4	300:400	1	300 PA - 200 GF		82% :18%	29	9300	
SSS3/MIX	8 : 6	300:400	0	0		50% : 25%	30	9600	
SSS4/MIX	6 : 7	300:400	0	0		70% :30%	29	9400	
SSS5/MIX	4 : 9	300:400	0	0		62.5% : 37.5%	29	9600	

*All the calculations for the thermoplastic percentage to the reinforcement ones are for the sheath only regardless the core as three different types of cores have been used with each sheath: 100% reinforcement, 100% thermoplastic and 50% reinforcement:50% thermoplastic.

- 2.2.4. The fourth stage(D):

Choosing the best performing blends from the most promising resin which was the polypropylene (PP) and then try them again, but with replacing the used fiberglass yarns with a pretreated fiberglass yarns with a definite type of silane compatible with thermoplastic yarns. Two types of pretreated fiberglass yarns were imported from AGY company based in the U.S.A, the commercial name of the used silane was “561 sizing”. Tables 12 and 13 represent the operating variables used while producing the fourth stage samples.

The most effective fiber volume fraction was then selected, which has been obtained by using the ratio of 40% fiberglass and 60% thermoplastic to perform the last stage’s samples using the pre-treated two types of fiberglass (E-glass & S-glass) with compatible silane (sizing 561) in order to enhance the performance of the resulted braided fiber posts.

Table 12 stage four braiding configuration of E-Glass (+ silane) braided with PP yarns

Sample Code	PP: E-GF Spindles	PP: E-GF Count	PP:GF Percentage	Total spindles	Total counts	Core
EGSS1/GF	12 : 4	300 : 600	60% : 40%	16	6000	6 GF yarns each 2800 = 16800 Denier /GF
EGSS1/PP	12 : 4	300 : 600	60% : 40%	16	6000	7*2400 PP = 16800 Denier/PP
EGSS1/MIX	12 : 4	300 : 600	60% : 40%	16	6000	3 GF yarns each 2800 = 8400 Denier ,+ (3*2400) PP+ 1200 PP = 8400 PP , TOTAL= 16800 Denier/MIX

Table 13 stage four braiding configuration of S-Glass (+ silane) braided with PP yarns

Sample Code	PP: S-GF Spindles	PP: S-GF Count	PP:GF Percentage	Total spindles	Total counts	Core
SGSS1/GF	12 : 4	300 : 600	60% : 40%	16	6000	6 GF yarns each 2800 = 16800 Denier /GF

SGSS1/PP	12 : 4	300 : 600	60% : 40%	16	6000	7*2400 PP = 16800 Denier/PP
SGSS1/MIX	12 : 4	300 : 600	60% : 40%	16	6000	3 GF yarns each 2800 = 8400 Denier ,+ (3*2400) PP+ 1200 PP = 8400 PP , TOTAL= 16800 Denier/MIX

2.2.5. Resin melting and Preform Formation: The produced braids have been placed in an aluminum custom-made mold after being cut from the braiding machine. The mold was grooved with two different diameters (1.5 – 2 mm) 10 grooves per each diameter (figure 2). Two similar molds were used throughout the melting process to accelerate the production process.

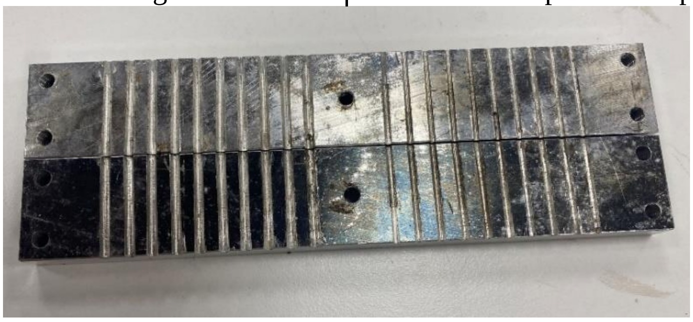

Figure 2 Aluminum Mold

These two molds with the braided performs inside have been placed in a digital oven (figure 3) after reaching the melting temperature of the used thermoplastic for almost 40 minutes (± 5 min) in order to obtain the final shape of the post. Then, after the mold has been cooled, the posts were removed out of the mold using a very thin needle. The fabrication method used for producing the novel posts understudy is represented in the next flowchart (figure 4) to illustrate the main processes in the whole manufacturing process.

Figure 3 Digital Oven

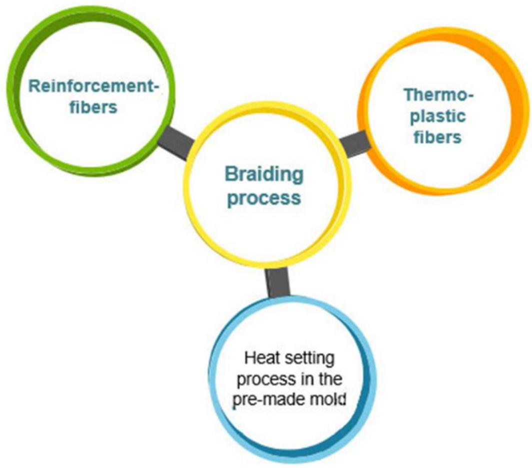

Figure 4 Flowchart representing the processes of the composite fabrication method

2. Testing:

Visual assessment for the resulted posts of the main different groups which are differentiated according to t their matrix (PET, PP, and PA) has been done. Moreover, two types of the mechanical testing have been performed to representative samples (n=20) of each group from the three different groups to find out their mechanical performance compared to the commercial fiber post and the tooth dentine. The two mechanical tests were three pending points test to find out the flexural modulus[15–17] and the other is the 45 degrees' compression test for the compression strength[18–20]. Results shown in table (14).

3- Results:

The best group visually was the PP posts in terms of integrity, less voids, straightness, and compactness. While the PET posts show brittleness, less integrity, and less compactness. Additionally, PA posts show the least integrity between the two types of yarns after the melting process with less brittleness than the PET posts. Figure (5) a, b, and c show the three types of the resulted posts.

(A) PET (B) PP (C) PA

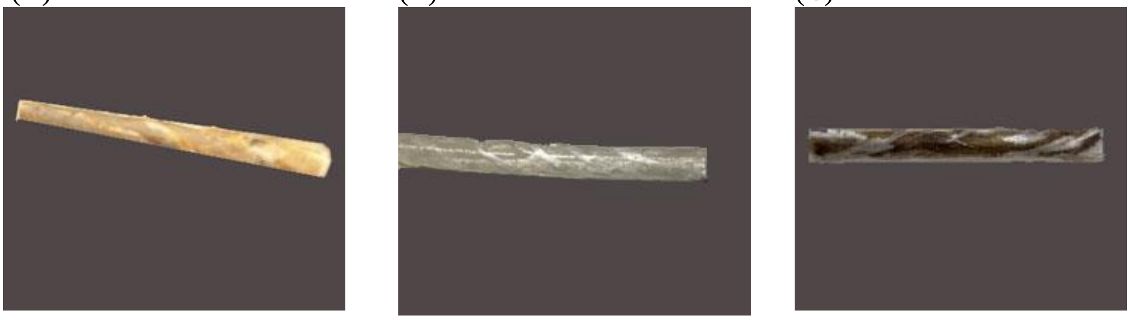

Figure 5 Real photos of the resulted posts: a(PET), b(PP), and c(PA)

Mechanical testing results are shown in table 14 which revealed that the best values were for the PP posts then the PA posts while the PET post show the least values for both the flexural Modulus and the compression strength.

Table 14 Summary of results obtained from mechanical tests performed

Type of Test	Test Results (average, n=20)			Co-efficient of Variation (%)		
	PET	PP	PA	PET	PP	PA
Flexural Modulus (GPa)	5.73	19.46	9.12	27.8	6.4	23.8
Compression Strength (MPa)	12.22	48.74	16.75	25.49	7.9	21.82

4- Discussion:

PP posts showed the best testing results in both visual assessment and mechanical testing, PET posts show the least values in the mechanical testing and the most brittle forms in the visual assessment, while the PA posts show better mechanical values than the PET post, but yet very low values compared to the commercial posts and also show the least homogenous form of the posts in the visual assessment.

These results could be inferred due to the different rheology property of the thermoplastic PP, PET, and PA, this fact resulted in better performance of the PP posts after the melting process in the post's fabrication method used in this paper[12,21–23]. This Fact also affected the final posts mechanical properties as shown in table (14) which revealed that the best mechanical properties were also for the PP posts while the PET posts show the most brittle forms and the least values for the mechanical testing. Additionally, the PA posts were affected by the less integrity between the two components of the post (PA and GF yarns) and show medium results, but yet less than the required values for the dental posts.

The PET posts brittleness may be attributed to the manual fabrication method used in this current approach which could have caused an accumulation of humidity because of less applied pressure of the mold while being in the oven[24,25]. This could have been remedied if an autoclave has been used or even more refined fabrication method[14].

PA posts showed more voids than the other two types and more delamination between the thermoplastic yarns, after being melted, and the GF yarns[26,27]. This problem could have been avoided or decreased if suitable coupling silane has been added to the other two types of the used yarn (thermoplastic and glass-fiber) before the melting process[28–31]. Accordingly, further studies are needed to evaluate the suggested improvements to the fabrication process.

5- Conclusion:

Braiding technology is a suitable alternative for the composites fabrication process and could provide versatile applications for composite materials through monitoring its various variables and parameters.

Moreover, Composite rods or posts could be achieved through a simple fabrication method consisting of two sequential steps of braiding and

melting processes. Different considerations have to be taken to achieve the optimum fabrication results; like the different braiding parameters (braiding angle, braiding dimensions, braiding types, etc.), braiding components (yarns) specifications and their share in the whole braided form, melting temperature (regarding the used thermoplastic yarns), and the applied pressure on the braided form while in the mold during the melting process.
Additionally, PP posts showed the best performance visually and mechanically using the novel fabrication method which have been discussed in this paper due to the intrinsic properties of the PP thermoplastic yarns and also due to the different drawbacks of the used manual fabrication process which could have been avoided if a more refined fabrication processes have been followed.

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