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Effect of Grain Distribution on Resin Consumption and Mechanical Performance of GRP Pipes

Şevki EREN*[1], Özcan ÇAĞLAR[2], Neslihan GÖKÇE[2], Azime SUBAŞI[2], Serkan SUBAŞI[2]

Abstract

It was aimed to produce glass fiber reinforced pipes (GRP), having less resin consumption and higher mechanical properties by changing the grain distribution of fillers used in the core region. American Foundry Society (AFS) grain fineness number currently used in GRP pipe production, and the grain distribution determined to the Fuller equation, the exponent of which is 0.8 (F 0.8), were used in the study. Chopped glass fibers, unsaturated polyester resin, and silica filler were used. It was manufactured three GRP pipes having 6 m length and nominal diameter (DN) of 350 mm by centrifugal casting technique. Initial specific ring stiffness and longitudinal tensile strength (LTS) tests were conducted on GRP pipes. After the longitudinal tensile tests of the produced GRP pipes, SEM images were taken from the core region and the morphological analyzes of the images were made. As a result of the study, when GRP pipes are produced incorporating 14 % less body resin in F 0.8 grain distribution, 44.11 % higher stiffness and 50.4 % higher LTS was obtained than the minimum value required in the standard.

Keywords: GRP pipe, filler materials, grain distribution, AFS grain fineness number, Fuller equation.

1. INTRODUCTION

Glass fiber reinforced pipes (GRP) are generally three-layered composite systems. These composite systems consist of thin FRP layers on the inner and outer surfaces of the pipe walls and a polymer mortar layer in the center [1],[2],[3]. These pipes are produced by centrifugal casting (CC) or filament winding (FW) methods [2],[3],[4],[5]. GRP pipes must provide certain design criteria, including short-term hydrostatic failure strength, representing the longitudinal tensile strength (LTS) and initial specific ring stiffness [2],[5]. The primary purpose of fillers is to restrict the movement of the polymer chain, thereby increasing hardness, abrasion resistance, stiffness, and strength but reducing ductility [6],[7],[8]. Glass fiber reinforced polymer composite with particle-filled is formed by combining glass fiber and mineral aggregates with a resin system [9]. For this reason, GRP pipe manufacturers prefer to apply a filling layer impregnated between the FRP layers as an economical alternative method [2]. AFS grain fineness

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number is a grain distribution type used as a general indication of sand fineness by most foundries in the United States and calculated from the grain distribution determined by standard ASTM sieves [10]. Each fraction is multiplied with a weighting factor, the results are added together and divided by 100. AFS grain fineness number gets bigger as the average size decreases and is considered to be proportional to the number of grains per unit weight [11]. AFS 35 (390 µm), AFS 40 (340 µm), AFS 45 (300 µm), AFS 50 (280 µm), AFS 55 (240 µm), AFS 60 (220 µm), AFS 65 (210 µm), AFS 70 (195 µm), AFS 80 (170 µm), AFS 90 (150 µm), etc. different AFS grain fineness numbers have been currently using in the industry [10]. GRP pipes and grain distributions have been investigated by several researchers;

In the research conducted by Rafiee [2] it has been reported that the effect of adding sand filler into the polymer matrix as a core layer on the mechanical properties of GRP pipes has not been investigated enough by researchers. Kumar et al. [12] has selected the silica sand with the range of AFS 60-140 grain fineness number to explore its potential effects on tensile properties of Al–7 % Si alloy castings made by the EPC process. They determined that the grain fineness number and pouring temperature importantly affect the tensile strength and elongation percentage after a fracture. Fuller and Thompson [13] underlined the important effect of aggregate grain distribution on the physical and mechanical properties of concrete. The problem of the best possible grain distribution of aggregates and their contribution to optimum proportioning for the concrete mixture has been the issue of numerous experimental and theoretical investigations. Shi and Wei [14] examined the mechanical properties of glass fiber reinforced plastic mortar pipes with an inner diameter of 1500 mm under different loading conditions. In their study, ring and axial compressive strength and elastic modulus, stiffness and fatigue test were carried out. It was determined that the pipe stiffness was determined as 2.3 MPa. As a result, it was concluded that the composite with resin and quartz sand, increase the compression strength and the effect of quartz sand on compressive strength is more important than the resin and glass fiber. Rafiee and Reshadi [15] simulated and analyzed the functional failure in composite pipes exposed to internal hydrostatic pressure. A progressive damage modeling was developed considering the effect of the core layer added for increasing the pipe stiffness. The effect of two primary parameters as core thickness and the winding angles of cross plies were studied. It was observed that first-ply-failure and functional failure pressures increase linearly as the core thickness increase. Gökçe et al. [16] analysed the effects of the type of resin and fiber on the mechanical behaviours of the polymer composite pipe manufactured by the CC technic. Isophthalic, ortophthalic, and vinyl ester resin were used as matrix material, E and ECR glass fiber were used as reinforcement material, and silica sand was used as filler material. As a result, it was found that the mechanical behaviours of the polymer composite pipes changed with different types of resin and fiber.

In this study, it was aimed to manufacture GRP pipes having less resin consumption and higher mechanical properties by changing the grain distribution of the fillers used in the core region.

2. EXPERIMENTAL

2.1. Matrix Materials

Orthophthalic body resin (Boytek BRE 310) and orthophthalic liner resin (BRE 816) were used in GRP pipe production. Cobalt octoate (Co: $C16H30CoO4$) (wt. 1 %) as an accelerator and methyl ethyl ketone peroxide (MEKP: $C8H18O6$) (wt. 1 %) as an initiator were used as additive materials. Some mechanical properties of orthophthalic body resin are given in Table 1.

Table 1 Physical and mechanical properties of orthophtalic body resin

Property	**Unit**	**Orthophthalic Resin**
Density	-	1.12
Viscosity	(cp)	250
Solid content	(%)	57
Tensile modulus	(MPa)	3550
Tensile strength	(MPa)	74
Flexural strength	(MPa)	125
Flexural modulus	(MPa)	3800
Elongation at Break (tensile)	(%)	3.15
Total volumetric shrinkage	(%)	8.0

2.2. Filling Materials

Silica sand with AFS 40-45 grain fineness number (SiO_2: 98.94 %; Al_2O_3: 0.08 %; Fe_2O_3: 0.1 %) currently used by Superlit Pipe Industry Inc. as filling material in GRP pipe production were used, and the grain distribution determined to the Fuller equation was used in the study. The physical properties of silica sand are given in Table 2.

Table 2 Physical properties of silica sand

Physical properties	Silica sand
Moisture content (%)	0.002
Relative density	2.55
Burning loss (%)	1.3
Dry specific gravity	2.55
Specific gravity saturated with water	2.61
Loose unit weight (g/cm³)	1.616
Cramped unit weight (g/cm³)	1.791
Water absorption (%)	2.03
Specific surface area (m²/kg)	12.07
Average grain size (micron)	237

2.3. Fiber Materials

Chopped E-glass fiber was used in the study. The physical and mechanical properties of E-glass fiber are given in Table 3.

Table 3 Physical and mechanical properties of chopped E-glass fiber

Properties	Glass fiber
Moisture content (%)	0.92
Fiber weight (g/km)	2400
Binder content (%)	2.1
Number of ends	60
Fiber diameter (micron)	16-20
Specific weight	2.60
Tensile strength (MPa)	3400
Elasticity modulus (GPa)	77
Fiber length (mm)	50

2.4. Optimization of Filler Particle Distribution Used in GRP Pipe Production

Some early grain distribution design studies on polymer composites were performed using silica sands in different grain distributions determined according to the Fuller equation and also in AFS 40-45 grain fineness number. As a result of the tests on the polymer composites, the best grain distribution, which has the minimum resin consumption and the best compressive strength, was determined as F0.8 [17]. It has been concluded that the use of this distribution in GRP pipe production will be appropriate. The Fuller equation used in the study is given in Equation 1 [13].

$$P\,\% = (d / D)^n \qquad (1)$$

P%: total percent of particles passing through (or finer than) sieve

d: diameter of the current sieve,

D: maximum size of aggregate (1000 µm)

n: exponent of the equation, (n=0.8 for this study)

However, since F 0.8 grain distribution is not available in the market, silica sands with AFS 40-45 and AFS 110-140 grain fineness number that is available in the market were mixed to obtain F 0.8 grain distribution. For this reason, as a result of the grain distribution analysis, a new optimized mixture was formed by taking the proportion of 20 % of AFS 110-140 grain fineness number and 80 % of AFS 40-45 grain fineness number by weight and this mixture was called as F 0.8 (optimization 1). It was concluded that the new mixture optimized is the closest grain distribution to F 0.8 grain distribution. The grain sizes of the sands used are in the range of 0-1000 microns. F 0.8 filler grain-size distributions used in the study are represented in Table 4 and different AFS and F 0.8 (optimization 1) filler grain-size distributions are represented in Table 5. A visual of all filler grain-size distributions graphic used in the study are represented in Figure 1.

Table 4 F 0.8 filler grain-size distributions

Grain sizes (μm)	P, % F 0.8
1	0.4
10	2.5
100	15.8
150	21.9
180	25.4
250	33
300	38.2
500	57.4
600	66.5
710	76
850	87.8
1000	100

Table 5 Different AFS and F 0.8 (optimization 1) filler grain size distributions

Grain sizes (μm)	P, %		
	AFS 40-45	AFS 110-140	F0.8 (optimization 1) [AFS 110-140 (%20) + AFS 40-45 (%80)]
1	0	0	0
63	0	22	4
90	0	75	15
125	1	97	20
180	2	99.5	22
250	19	100	35
355	61	100	68
500	89	100	91
600	94	100	95
710	98	100	99
850	99	100	99
1000	100	100	100

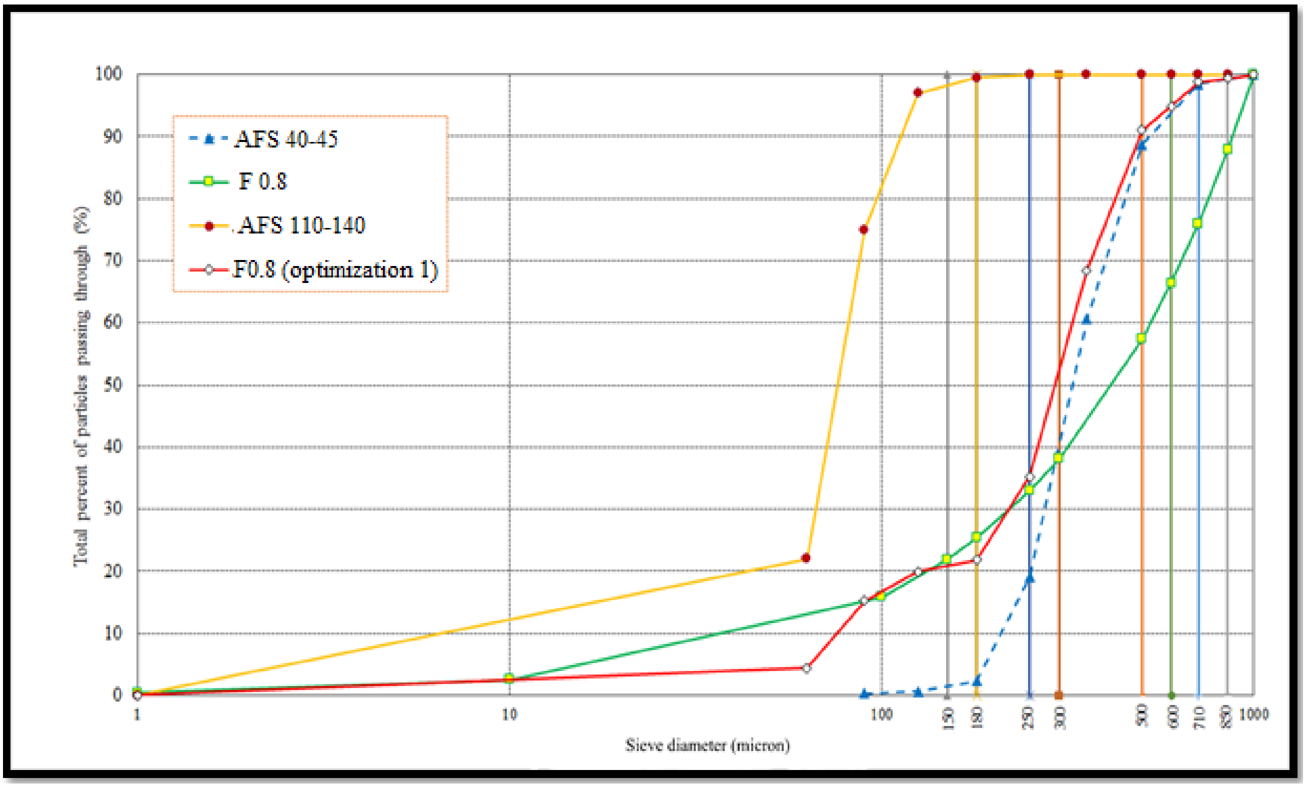

Figure 1 Different filler grain size distribution graphics used in the study

2.5. Manufacture of GRP Pipe

In this study, the CC method was preferred to produce GRP pipes in a standard way when the optimized mineral filling material mixture is started to mass production. It was produced three GRP pipes, having 6 m length and DN of 350 mm. GRP pipes were aimed to be exposed to a nominal pressure (PN) of 6 bar, have a nominal stiffness (SN) of at least 10.000 N/m^2, and the LTS value of at least 135 N/mm. The pipe production process by the CC method can be seen in Figure 2.

Figure 2 GRP pipe production process by the CC method

Since the grain distributions of each pipe produced are different, the pipe types were numbered from 1 to 3. Necessary explanations regarding the raw material usage amounts of the related pipes produced using different grain distributions are described below.

Pipe No (1) (Reference Pipe):

The reference pipe has been currently manufacturing by Superlit Pipe Industry Inc. chopped E-glass has been using as fiber reinforcement, and silica sand with AFS 40-45 grain fineness number has been using as filler material in this reference pipe production.

Pipe No (2):

In pipe no 2, chopped E-glass was used as fiber reinforcement, and silica sand with F0.8 (optimization 1) grain distribution was used as filler material. In this pipe type, the pipe production was carried out by incorporating 3.5 % less body resin than the amount of resin used in the reference pipe.

Pipe No (3):

In pipe no 3, chopped E-glass was used as fiber reinforcement, and F 0.8 (optimization 1) grain distributed silica sand was used as filler material. In this pipe type, the pipe production was carried out by incorporating 14 % less body resin than the amount of resin used in the reference pipe.

The pipe no 1 was called as the reference pipe. Initial specific ring stiffness and the LTS tests were performed on the produced pipes. The schematic representation of the pipe section produced by the CC method and a visual of the part cut from the produced pipes are shown in Figure 3. The duties of the layers specified in the pipe section are given in Table 6 [18].

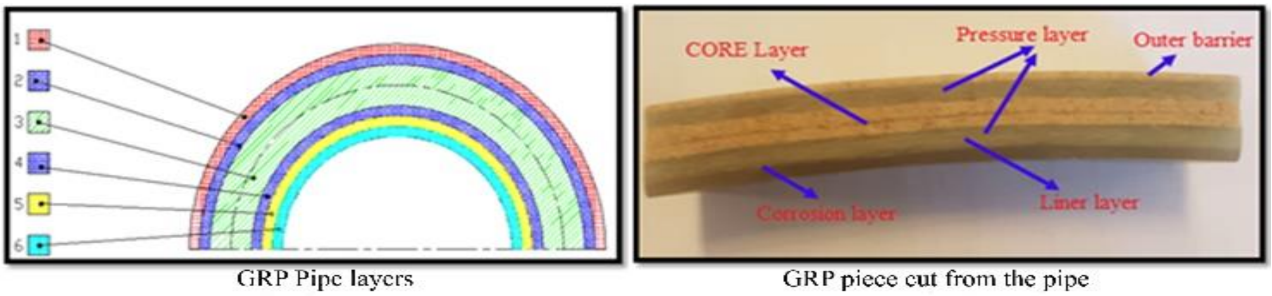

Figure 3 The schematic representation of the pipe section produced by the CC method and a visual of the part cut from the produced pipes

Table 6 Duties of the layers specified in the pipe section

Pipe Layer No	Function	Content	Thickness
1	An outer surface protective layer (outer barrier) (UV, chemicals, impact resistance, etc.)	Resin and sand	Min. 1 mm
2	Pressure layer	Resin and chopped fiber	While the wall thickness is increased to achieve high pressure, the thickness of the layers in this region is also increased.
3	CORE (filler zone) - stiffness zone	Resin, sand and small amount of chopped fiber	
4	Pressure layer	Resin and chopped fiber	While the wall thickness is increased to achieve high pressure, the thickness of the layers in this region is also increased.
5	Liner layer to ensure sealing	Resin and chopped fiber	
6	An inner surface protective layer (corrosion layer)	Pure Resin	Min. 1 mm

In GRP pipes, "resin + sand + chopped fiber" materials are used in the third layer, which is defined as the filling layer (CORE), to increase the stiffness performance. In these GRP pipes, the thicker pipe walls are necessary to increase the apparent pipe stiffness [2],[18].

2.6. Initial Specific Ring Stiffness

Initial specific ring stiffness test was carried out according to ISO 7685: 2019 was used as the reference specified in the relevant standard [19]. In the study, the stiffness samples were cut from the mold removal part and feeding part of GRP pipes. The outer diameter of the pipe was measured with a caliper on the stiffness samples and measurements were recorded. Subsequently, a deflection of 3 % was applied to the stiffness samples and deflection values recorded 2 minutes later and then the stiffness values were calculated.

The stiffness test samples of GRP pipes are given in Figure 4.

Figure 4 The stiffness test sample images of GRP pipes

2.7. Longitudinal Tensile Strength Test

ISO 8513: 2016 Method (A), was used to determine the LTS value of the pipe samples [20]. 5 longitudinal tensile test samples were cut in a longitudinal direction from GRP pipes, and the LTS test was carried out. A visual of specific ring stiffness and the LTS test is given in Figure 5.

Figure 5 A visual of the specific ring stiffness and the LTS test

3. RESULTS AND DISCUSSIONS

3.1. Raw Material Usage Amounts in GRP Pipes

Raw material usage amounts according to pipe diameter and nominal pressure values of the GRP pipes are given in Table 7.

Resin reduction amounts were determined by foresight in this study. Of course, different resin reduction ratios can be used.

3.2. Initial Specific Ring Stiffness Test Results

Average initial specific ring stiffness values of GRP pipes, which are produced in different filler grain distributions and numbered from 1 to 3, are given in Table 8 and Figure 6.

Table 7 Raw material usage amounts of GRP pipes

DN/PN/SN ($mm/bar/N/m^2$)	**Pipe No**	**Fiber**	**Grain Distribution Type**	**Body + Liner Resin (kg)**	**Total resin (kg)**	**Fiber amount (kg)**	**Filler amount (kg)**	**Total weight (kg)**
350/06/10.000	Pipe No: (1) (Reference)	E- glass	AFS 40-45	**29**+14	43	16,6	77,1	136,7
	Pipe No: (2)	E- glass	Fuller 0.8	**28**+14 **(incorporating 3,5% less body resin)**	42	16,2	81	139,2
	Pipe No: (3)	E- glass	Fuller 0.8	**25**+14 **(incorporating 14% less body resin)**	39	16,2	79,8	135

Table 8 Average initial specific ring stiffness values of GRP pipes

DN/PN/SN ($mm/bar/N/m^2$)	**Pipe No**	**Fiber**	**Grain Distribution Type**	**Stiffness (N/m^2)**					
				Range	**Min.**	**Max.**	**Std. Error**	**Std. Dev.**	**Average**
350/06/10.000	Pipe No: (1) (Reference)	E glass	AFS 40-45	1626	14581	16207	334	668	15.369
	Pipe No: (2)	E glass	Fuller 0.8	2271	15361	17632	494	988	16.697
	Pipe No: (3)	E glass	Fuller 0.8	1710	13453	15163	339	758	14.411

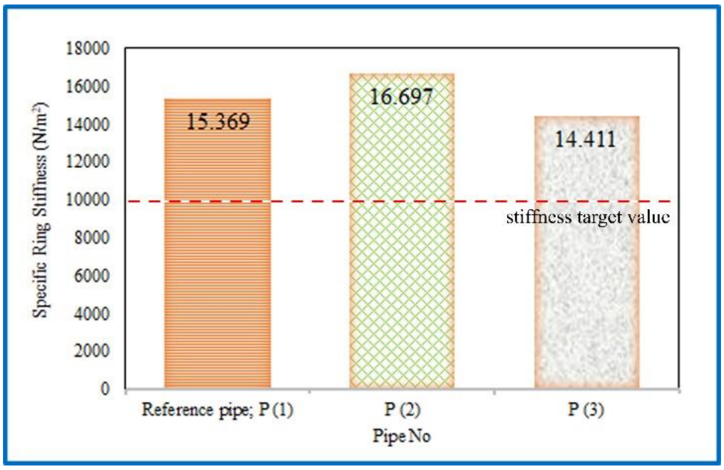

Figure 6 Change of the stiffness values according to the pipe type

It was determined that all GRP pipes produced within the scope of the study reached the minimum stiffness value of 10.000 N/m2 required in the standard and even higher stiffness values.

In the pipe number 2 with F 0.8 (optimization 1) grain distribution, which is used as an alternative to AFS 40-45 grain fineness number, 8.64 % higher stiffness was obtained by incorporating 3.5 % less body resin compared to the reference pipe production.

In the pipe number 3 with F 0.8 (optimization 1) grain distribution, a reduction of 6.23 % in the stiffness was obtained by incorporating 14 % less body resin compared to the reference pipe production, but 44.11 % higher stiffness value was obtained than the minimum stiffness value of 10.000 N/m2 required in the standard.

As the stiffness test results, it was concluded that it is possible to produce GRP pipes with F 0.8 (optimization 1) grain distribution at a lower cost by providing up to the ratio of 14 % resin consumption.

3.3. LTS Test Results

Average LTS values of GRP pipes are given in Table 9 and Figure 7.

It was determined that all GRP pipes produced within the scope of the study reached the minimum LTS value of 135 N/mm required in the standard and even higher strength values.

Table 9 Average LTS values of GRP pipes

DN/PN/SN (mm/bar/N/m^2)	Pipe No	Fiber	Grain Distribution Type	LTS (N/mm)					
				Range	Min.	Max.	Std. Error	Std. Dev.	Average
350/06/10.000	Pipe No: (1) (Reference)	E glass	AFS 40-45	57	190	247	16.895	29.263	214.97
	Pipe No: (2)	E glass	Fuller 0.8	32	199	231	8.010	16.020	212.98
	Pipe No: (3)	E glass	Fuller 0.8	26.1	185.8	211.9	8.6834	15.0401	203.167

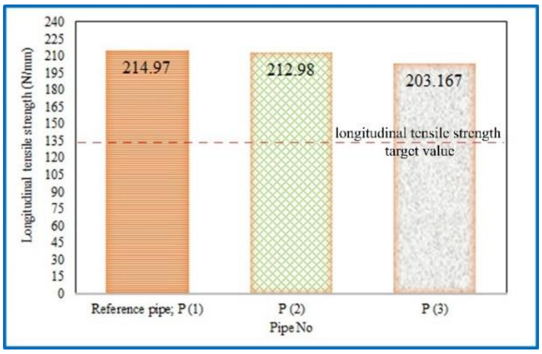

Figure 7 Change of the LTS values according to the pipe type

In pipe number 2 with F 0.8 (optimization 1) grain distribution, 57.8 % higher LTS value was obtained than the minimum LTS value of 135 N/mm required in the standard by incorporating 3.5 % less body resin.

In pipe number 3 with F0.8 (optimization 1) grain distribution, 50.4 % higher LTS value was obtained than the minimum LTS value of 135 N/mm required in the standard by incorporating 14 % less body resin.

As the LTS test results, it was concluded that it is possible to produce GRP pipes with F 0.8 (optimization 1) grain distribution at a lower cost by providing up to the ratio of 14 % resin consumption.

Kumar et al. [12] determined that the grain fineness number and pouring temperature importantly affect the tensile strength. Fuller and Thompson [13] underlined the important effect of aggregate grain distribution on the physical and mechanical properties of concrete. In this study, a better grain distribution was obtained by using the F 0.8 (optimization 1) grain distribution in the core region in GRP pipe production and for this reason, it was concluded that F 0.8 (optimization 1) grain distribution is effective in reducing resin consumption.

3.4. SEM Images and Morphological Analysis of GRP Pipes

- After the longitudinal tensile tests of the produced GRP pipes, SEM images were taken from the core region and the morphological analyzes of the images were made. SEM images in the core region of AFS 40-45 and F 0.8 (optimization 1) grain distributed GRP pipes are shown in Figure 8 and Figure 9 respectively.

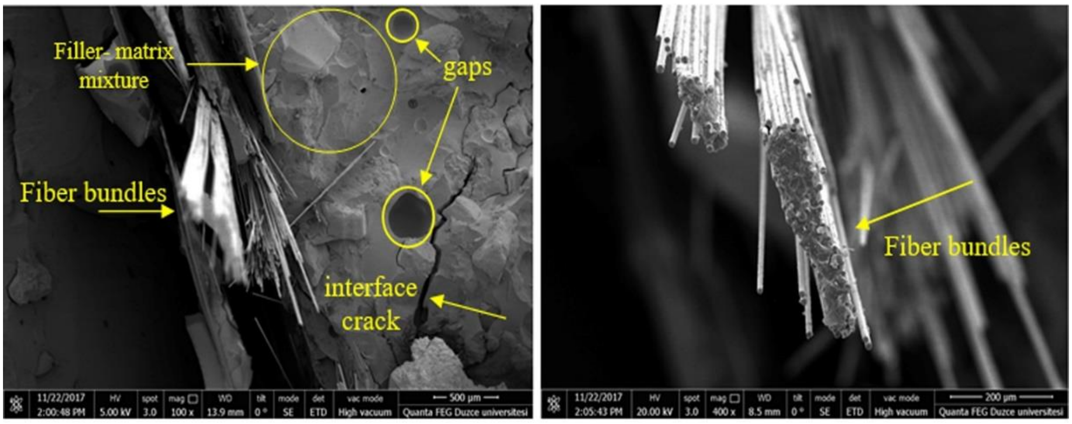

Figure 8 SEM images in the core region of AFS 40-45 grain distributed GRP pipes

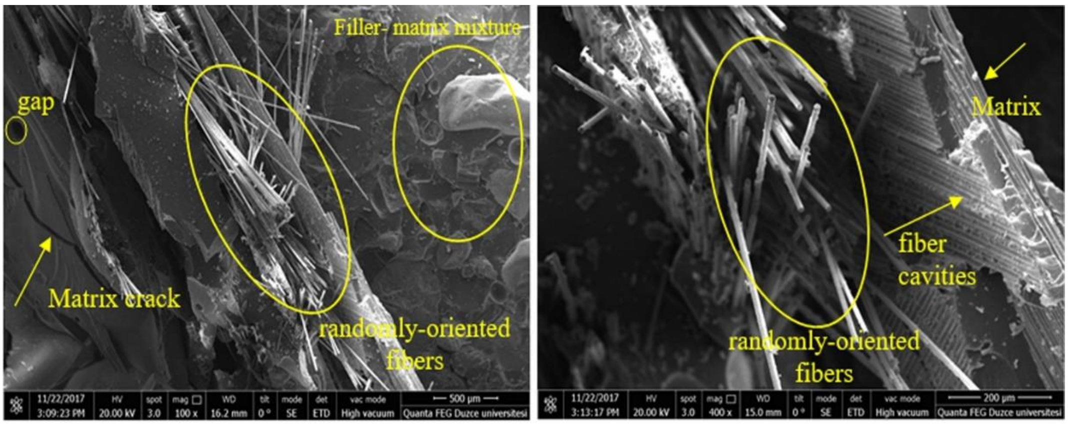

Figure 9 SEM images in the core region of F0.8 grain distributed GRP pipes

When the SEM images in the core region of AFS 40-45 grain distributed GRP pipes in Figure 8 were examined, it was observed that there were air gaps and matrix cracks. However, it has been observed that the fillers are homogeneously distributed, and the random orientation of the fibers is good. The increase in tensile strength of composites is due to the increase in fiber content, due to the fact that fibers play an important role in tensile strength and their ability to resist crack propagation. When the Initial Specific Ring Stiffness and LTS test results of AFS 40-45 grain distributed GRP pipes are evaluated, it is thought that the amount of fiber used for this mixture is enough to fulfill this task.

When the SEM images in the core region of F 0.8 (optimization 1) grain distributed GRP pipes in Figure 9 were examined, it was observed that the fillers were homogeneously distributed, and the random orientation of the fibers is good. In addition, it was observed that the matrix structure was adhered on the surface of the broken fiber pieces and fiber cavities were formed on the broken matrix surface. When this situation is evaluated together with the Initial Specific Ring Stiffness and LTS test results of GRP pipes with

F 0.8 (optimization 1) grain distribution, it is understood that the matrix and fiber interface bond strength is strong. Considering these results, it was concluded that it is possible to use lower rates of resin in GRP pipes with F 0.8 (optimization 1) grain distribution in this study.

4. CONCLUSIONS

In this study, silica sands with AFS 40-45 grain fineness number currently used in GRP pipe production were used, and alternatively, F 0.8 grain distributions were used to reduce the resin consumption and increase the mechanical properties. As a result of the study;

It was determined that mechanical properties such as stiffness and longitudinal tensile strengths decreased as a result of reducing the amount of resin. However, all GRP pipes produced within the scope of the study reached the minimum stiffness, and the LTS value required in the standard and even higher values.

In the pipe number 2 with F 0.8 (optimization 1) grain distribution, 8.64 % higher stiffness was obtained compared to the reference GRP pipe production and 57.8 % higher LTS value was obtained than the minimum LTS value of 135 N/mm required in the standard by incorporating 3.5 % less resin.

In the pipe number 3 with F 0.8 (optimization 1) grain distribution, 44.11 % higher stiffness value was obtained than the minimum stiffness value of 10.000 N/m2 and 50.4 % higher LTS value was obtained than the minimum LTS value of 135 N/mm required in the standard by incorporating 14 % less resin.

As a result of the study, when GRP pipes are produced incorporating 14 % less resin in F 0.8 (optimization 1) grain distribution, 44.11 % higher stiffness and 50.4 % higher LTS value was obtained than the minimum value required in the standard.

In other words, it was concluded that F 0.8 (optimization 1) grain distribution is effective in reducing resin consumption, and it is possible to produce GRP pipes with F 0.8 (optimization 1) grain distribution at a lower cost by providing up to the ratio of 14 % resin consumption.

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The Declaration of Conflict of Interest/ Common Interest

The authors declare that they have no known competing for financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors' Contribution

The authors contributed to the study as follows. Şevki EREN: Investigation, Writing- Original draft preparation, Methodology, Formal analysis (35 %), Özcan ÇAĞLAR: Conceptualization, Methodology (20 %), Neslihan GÖKÇE: Conceptualization, Methodology (15 %), Azime SUBAŞI: review & editing, Visualization, Validation (15 %), Serkan SUBAŞI: Methodology, Supervision, Project administration (15 %).

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment.

REFERENCES

[1] Jin NJ, Hwang HG, Yeon JH, "Structural analysis and optimum design of GRP pipes based on properties of materials", Constr Build Mater., vol. 38, pp. 316–26, 2013. https://doi.org/10.1016/j.conbuildmat..07.115.

[2] Rafiee R, "On the mechanical performance of glass-fibre-reinforced thermosetting-resin pipes: A review", Compos Struct., vol.143, pp. 151–64, 2016. https://doi.org/10.1016/j.compstruct.2016.02.037.

[3] Zoghi M, "The International handbook of FRP composites in civil engineering", CRC Press., 2013.

[4] Farshad M, Necola A, "Strain corrosion of glass fibre-reinforced plastics pipes", Polym Test., vol.23, pp. 517–21, 2004. https://doi.org/10.1016/j.polymertesting.2003.12.003.

[5] Faria H, Guedes RM, "Long-term behaviour of GFRP pipes: Reducing the prediction test duration", Polym Test., vol. 29, pp. 337–45, 2010. https://doi.org/10.1016/j.polymertesting.2009.12.008.

[6] Road N, "A review of particulate reinforcement theories for polymer composites", Composites, vol. 23, pp. 376, 1992. https://doi.org/10.1016/0010-4361(92)90358-2.

[7] Mansour SH, Abd-El-Messieh SL, "Electrical and mechanical properties of some polymeric composites", J Appl Polym Sci., vol. 83, pp. 1167–80, 2002. https://doi.org/10.1002/app.2283.

[8] Agarwal BD, Broutman LJ, Chandrashekhara K, "Analysis and performance of fiber composites", John Wiley & Sons., 2006.

[9] Guerrini GL, "Applications of high-performance fiber-reinforced cement-based composites", Appl Compos Mater., vol. 7, pp. 195–207, 2000. https://doi.org/10.1023/A:1008994020916.

[10] Turkeli A, "Sand, sand additives, sand properties, and sand reclamation", Foundry Technology, http://mimoza.marmara.edu.tr/~altan.turkeli/files/cpt-2-sand_sand.pdf. (accessed 12/02/2021).

[11] Molding sand: image analysis of molding sand particle sizing in the foundry industry. https://www.microtrac.com/applications/knowledge-base/molding-sand/ (accessed 12/02/2021).

[12] Kumar S, Kumar P, Shan HS, "Optimization of tensile properties of evaporative pattern casting process through Taguchi's method", J Mater Process Technol., vol. 204, pp. 59–69, 2008. https://doi.org/10.1016/j.jmatprotec.2007.10.075.

[13] Fuller WB, Thompson SE, "The laws of proportioning concrete", Trans Amer Soc Civ Engrs Bd.,1907.

[14] Shi H, Wei L, "Laboratory evaluation on performance of glass fiber reinforced plastic mortar pipe culverts", Stavební Obz - Civ Eng J., vol. 27, pp. 60–71, 2018. https://doi.org/10.14311/cej.2018.01.0006.

[15] Rafiee R, Reshadi F, “Simulation of functional failure in GRP mortar pipes”, Compos Struct., vol. 113, pp.155–63, 2014. https://doi.org/10.1016/j.compstruct.2014.03.024.

[16] Gokce N, Yilmazer U, Subasi S, “Effect of fiber and resin types on mechanical properties of fiber-reinforced composite pipe”, Emerg Mater Res., vol. 8, pp. 452–8, 2019. https://doi.org/10.1680/jemmr.18.00093.

[17] Ş. Eren, S. Subaşı, “A research on the production of hybrid fiber and mineral reinforced high-performance polymer composite material”, PhD Thesis, Duzce University, Institute of Science, Interdisciplinary Composite Materials Technologies Department, Düzce, Turkey, 2018.

[18] CC (Savurma Döküm) - Superlit Boru San. A.Ş. http://www.superlit.com/tr/teknoloji-ve-kalite/savurma-dokum-cc/ (accessed 12/02/2021).

[19] ISO (2019) 7685: Plastics piping systems-Glass-reinforced thermosetting plastics (GRP) pipes — Determination of initial specific ring stiffness.

[20] ISO (2016) 8513: Plastics piping systems — Glass-reinforced thermosetting plastics (GRP) pipes — Test methods for the determination of the initial longitudinal tensile strength.