Determination the properties of bitumen and resin impregnated geotextiles

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ABSTRACT: The excessive settlement, insufficient bearing capacity or stability problems occur with respect to increase in external loads on structural foundations or slope conditions. To solve these challenges reinforced soil applications have become crucial for the construction sector in terms of providing economical and effective solutions. In this study, it is aimed to increase the mechanical characteristics of geotextiles such as bearing capacity during separation purpose, puncture resistance, and tensile strength. Thus, three different types of woven geotextiles were impregnated with bitumen and synthetic resin, and the change in strength values compared to the original specimens and their effects on the bearing capacity of the soil were evaluated within plate loading tests. The load-displacement graphs were drawn by performing plate loading tests. Based on the results of another test performed, the tensile test, the innovative geotextiles demonstrated superior tensile strength and enhanced ductility relative to the reference geotextiles. The highest bitumen (1821 gr/m^2) and resin (4280 gr/m^2) impregnation rate was observed in PP 5000 H type of geotextile. According to different geotextile and impregnation types, values between 43.11% decrease and 20.82% increase were obtained at 10 mm settlement level in plate loading tests. Although the bitumen coating provided a large amount of resistance in terms of puncture resistance, the sufficient bearing capacity levels could not be obtained due to the brittle behavior of resin. When the tensile strength test results were examined, it was determined that impregnated geotextiles had properties that can provide both bearing capacity and tensile strength mobilization within geotechnical projects.

1 INTRODUCTION

Due to the increasing demands for different types of construction, such as residential expansion and transportation infrastructure, various ground improvement techniques are being applied in areas where soil conditions are inadequate. Since the soil parameters are insufficient, several soil improvement and reinforcement methods have been used to enhance bearing capacity and reduce settlement. Reinforced soil systems are one such method, involving the embedding of tensile elements within the soil in cases where increasing the tensile strength of soil is required. Reinforced soil applications are commonly used to address stability issues in slopes, embankments, and earthworks. In such cases, galvanized steel strips or geosynthetic reinforcements with high tensile strength and interfacial friction are applied to ensure the stability of soils subjected to relative movement, deformation or shearing. Owing to factors such as cost-effectiveness, improved manufacturing quality, ease of workability, and practical application, the use of geosynthetic reinforcements in geotechnical and transportation engineering has been steadily increasing. Because of their lightweight nature, ability to reduce overburden pressure, and effective performance against lateral earth pressure, geosynthetics are widely used in the construction industry (Erdincliler and Ozer, 2014; Evirgen et al., 2017; Güleç and Evirgen, 2023; Evirgen et al., 2024). Geosynthetics are planar products manufactured from polymeric materials in factories. Although geosynthetics represent a relatively recent development in geotechnical engineering, they are now extensively used to solve a wide variety of ground improvement and soil reinforcement problems. Another field of application for geosynthetics is the prevention of reflection cracking in bituminous asphalt pavements (Khodaii et al, 2009; Kumar and Saride, 2018; Evirgen et al., 2021).

Geotextiles, a subgroup of geosynthetics, play a significant role in ground improvement and soil reinforcement applications. The primary purpose of using geotextiles in soil is to enhance its strength, reduce displacements, and improve the overall stability of the system (Mohiuddin, 2004). Geotextiles, which have high tensile strength and controlled permeability, also serve purposes such as separation and drainage. By increasing tensile resistance and deformation capacity before failure, they contribute to soil reinforcement (Yılmaz and Eskişar, 2007). Studies focusing on geotextiles have mainly highlighted tension capacity, permeability capability, soil bearing capacity, settlement behavior, and interfacial friction (Iryo and Rowe, 2003; Recio and Oumeraci, 2008; Cheah et al., 2017).

Patel (1982) conducted experiments on sandy soil foundations reinforced with woven geotextiles to investigate their load–settlement behavior by varying reinforcement depth, thickness, and soil grain properties. The optimal initial reinforcement depth ratio was found to be approximately 0.47 times the footing width or depth, maximizing bearing capacity regardless of settlement.

Yasrobi et. al (2009) tested geotextile-reinforced sandy foundations in a 100×100×80 cm test cell using 20 cm diameter circular footings and 400 g/m² geotextile reinforcement, examining the effects of reinforcement length, depth, and size.

Panigrahi and Pradhan (2009) used natural fibre geotextile (geojute) to enhance the bearing capacity of sandy soil, finding maximum improvement when the reinforcement length was 3.5 times the footing width and embedded to half the footing width.

Correia and Bueno (2011) studied reflection crack control and methods to extend the lifespan of damaged pavements by placing bitumen-saturated nonwoven geotextiles between old and new pavement layers. Tensile and permeability tests showed a significant increase in tensile strength due to fibre-bitumen interaction, and even low bitumen contents were sufficient to notably reduce permeability, indicating these geotextiles also function as geomembrane-like barriers.

Correia and Zornberg (2014) aimed to determine the optimum bitumen content to achieve the best strength and stiffness characteristics in saturated geosynthetics. Experimental results demonstrated up to a 62% improvement in the ultimate tensile strength of the geosynthetics.

Dikmen (2013) proposed a faster, cost-effective method involving the placement of tensile-resistant geotextiles with adequate friction beneath foundations, improving bearing capacity and reducing settlements. Results from laboratory tests and Plaxis 3D finite element analyses were compared graphically.

In this study, the enhancement possibility of the bearing capacity, the settlement and the tension strength of conventional geotextiles used in actual soil layers were evaluated by impregnating three different types of woven geotextiles with bitumen and resin. Changes in tensile strength and effects on soil bearing capacity were evaluated through tension and plate load tests. In addition, the impregnation operation significantly increased the tear resistance of geotextiles with respect to the puncture tests on the specially produced setup (ASTM D6241).

2 RESEARCH SIGNIFICANCE

This study aims to develop alternative composite soil reinforcements by impregnating geotextiles, known for their relatively low tensile strength, with bitumen and resin. In addition to improve strength parameters, the study addresses common issues such as damage and tearing in geotextile applications. By improving geotextiles to perform multiple functions simultaneously, the study proposes a cost-effective and efficient solutions for practical applications in both bearing and pullout purposes. The limited prior research on the use of bitumen or resin impregnated geotextiles beneath foundations highlights the novelty and practical relevance of this work in improving both bearing capacity and durability.

3 GEOTEXTILES

Geotextiles are factory-produced materials widely used in filtration, drainage, separation, and reinforcement applications, including roads, drainage systems, retaining walls, and coastal protection. Their primary function is to resist tensile stresses in the soil and reduce construction costs. In geotechnical applications, they can also partially fulfil the role of membrane-like materials and often serve multiple functions simultaneously. However, improper application of geotextiles can lead to material damage, resulting in deformations and performance failures. Installation defects are common due to the lack of standardized installation procedures, and improper handling may cause punctures or tears that significantly reduce the performance of the geotextile. Field samples have shown inconsistent strength losses compared to unused specimens.

Environmental factors also play a critical role in geotextile performance. High temperatures during construction can exceed material degradation thresholds, while low temperatures may lead to brittleness. Geotextiles are exposed to various fluids in the soil, necessitating specific testing for expected chemical interactions. Additives introduced during manufacturing can enhance chemical resistance. Although water absorption has minimal impact on mechanical performance, high pH levels can degrade polyester, while low pH environments can damage polyamides. In addition, exposure to sunlight degrades organic materials such as polymers, reducing their physical properties over time. Therefore, it is believed that, under suitable conditions, the use of special types of synthetic resins or bitumen is considered to enhance durability in solving the mentioned problems individually.

4 MATERIALS AND METHOD

4.1 Materials

Two types of soil were used in the study to be silty sand (SM) and well-graded gravel (GW) soils type according to the Unified Soil Classification System (USCS) within the scope of modeling natural low bearing soil layer and well graded pavement layer according to the limit values specified in the Turkish Highway Technical Specifications, respectively. The geotechnical properties of the soils were determined through a series of tests conducted in accordance with related American Society for Testing and Materials (ASTM) standards. The experiments and their results are summarized in Table 1.

Table 1. Geotechnical parameters of soils.

Property	Unit	GW	SM
Liquid limit	%	15.35	46.09
Plastic limit	%	13.91	44.70
Plasticity index (PI)	%	1.44	1.39
Shrinkage limit	%	-	6.46
Maximum dry unit weight	kN/m^3	22.86	20.70
Optimum water content	%	7.10	11.67
CBR	%	32.23	7.86
Friction angle	°	54.30	35.40
Cohesion	kN/m^2	26.20	41.40
Specific gravity	-	2.75	2.61

According to the ASTM D2166/D2166M (2016) standard, the unconfined compression test yielded an average axial stress of 180.00 kPa at a strain level of approximately 0.07. Accordingly, the CBR value of the GW was determined to be 32.23%, while that of the SM was found to be 7.86%.

Three types of geotextiles provided by the consulting company were used in the experiments. Geotextile specimens were prepared in different sizes based on the test type as follows; 40cm×40cm for foundation application tests, 20cm×20cm for tensile strength tests, and 30cm×30cm for puncture tests. Specimens that were not subjected to any treatment in terms of impregnation are referred as 'reference geotextiles'. For the remaining samples, coating and impregnation were applied based on the unit area of each geotextile to ensure equal amounts of bitumen and resin were used. Fig. 1. shows the samples after coating with bitumen and resin.

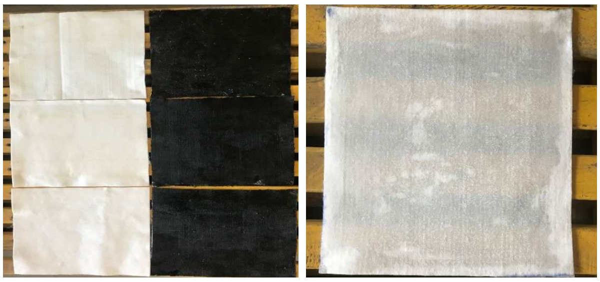

Figure 1. Geotextiles usen in the study; reference, bitumen and resin impregnated ones, respectively.

Table 2 presents the average impregnation ratios of bitumen and resin. The effects of ductile and brittle behavior on bearing capacity and tensile strength were investigated using both impregnated and reference geotextiles. Epoxisst Mega Slow Cure 30 type of synthetic resin, supplied by the consulting firm, was utilized in the coating process.

Table 2. Material properties of geotextiles.

	PS 5000	PP 5000	PP 5000 H
Mass (gr/m^2)	520 (±20)	500(-0/+40)	500(-0/+40)
Tensile Strength (kN/m)	≥18.2	31 (-4)	≥27
Elongation at Break (%)	≥50	≥50	≥50
Opening Size (mm)	0.055(±0.015)	0.075(±0.025)	0.075(±0.025)
Permeability (1/s.m^2)	30 (±15)	42 (±15)	42 (±15)
Ave. Bitumen Impregnation (gr/m^2)	1,499.5	1,751.9	1,821.4
Ave. Resin Impregnation (gr/m^2)	3,322.4	3,696.8	4,280.3

All samples were immersed into pools filled with bitumen and resin. To ensure that the specimens were coated with equal amounts of bitumen and resin, the materials used were adjusted by considering the quantity per unit area. After the impregnation process, the surfaces of the specimens were observed using a digital microscope. Small sections were extracted for observation, and the images of the samples are presented in Fig. 2. The formation, distribution and intensity of bitumen and resin absorption inside the geotextile fibres are visible clearly.

4.2 Methods

4.2.1 Tensile strength test

Tensile tests were conducted in the consulting company's laboratory to determine the tensile strength and ductility behaviours. The tests were conducted on reference and coated geotextile samples prepared with dimensions of 20cmx20cm, in accordance with TS EN ISO 10319 (2015). A total of 27 tensile tests were performed using 9 reference geotextiles, 9 resin-coated geotextiles, and 9 bitumen-coated geotextile samples (Fig. 2). The tensile strength test results are presented in Figs. 3–5.

Figure 2. Tensile strength test equipment.

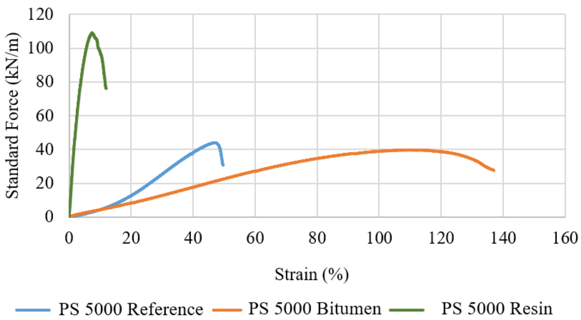

Figure 3. PS 5000, tensile strength test results.

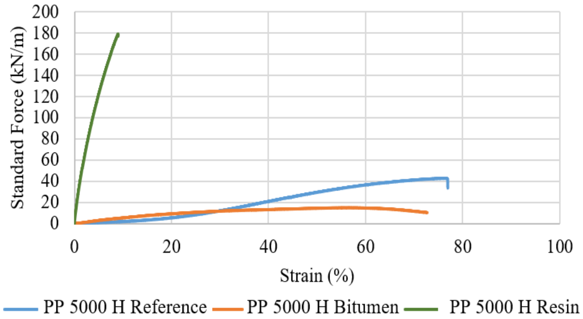

Figure 4. PP 5000 H, tensile strength test results.

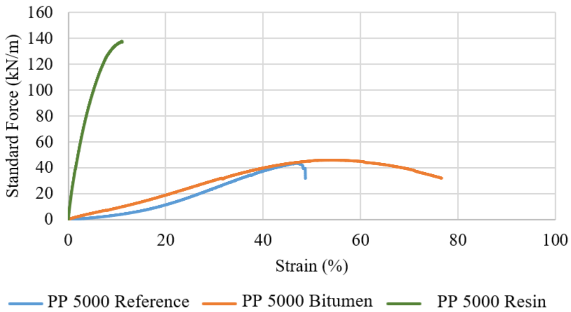

Figure 5. PP 5000, tensile strength test results.

4.2.2 Plate loading test

A polyvinyl chloride (PVC) cube test cell with a steel frame was prepared and insulated with foam for the plate loading tests. The net volume of the cell is 96,80 cm^3. Plate loading tests were conducted to evaluate the effects of both reference and coated geotextile specimens on the bearing capacity of the subsoil in foundation applications, as well as to assess potential damage sustained by the geotextiles beneath the foundation.

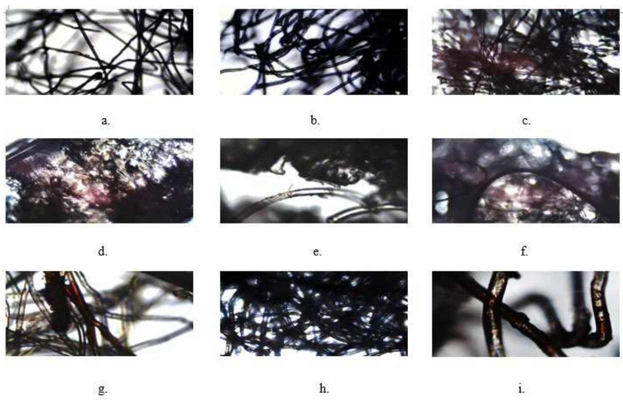

Figure 6. Microscope images of geotextiles: a. Ref PS 5000; b. Ref PP 5000; c. Ref PP 5000 H; d. PS 5000 with resin; e. PP 5000 with resin; f. PP 500 H with resin; g. PS 5000 with bitumen; h. PP 5000 with bitumen; ı. PP 5000 H with bitumen.

A total of nine tests were performed: three with reference geotextiles, three with resin-coated geotextiles, and three with bitumen-coated geotextiles. To ensure continuity in the soil structure, the inner surfaces of the test cell were lined with a double layer of expanded polystyrene (EPS) foam, and a thin layer of oil was applied to the foam surfaces. Although wall friction was theoretically expected to have no influence in the test setup due to 1/5 geometrical ratio, a layer of grease and double EPS foam was applied to the inner surfaces in order to eliminate any potential surface contact or minor frictional effects, thereby ensuring continuity and reliability of the experimental results. During tests, a hydraulic piston, a 100 kN capacity load cell, and two displacement transducers (LVDT) were used to measure surface settlement values corresponding to the applied vertical loads. Data were collected using a data logger.
The lower three-quarters of the test cell was filled with SM, while the upper one-quarter was filled with GW up to the surface. To achieve the required compaction according to the proctor tests, the soil was placed in four layers and compacted using a 6 kg hammer dropped freely from a height of 1 m, with 100 blows per layer. The plate loading tests via 10 cm plate in diameter were then repeated with both the original and coated geotextiles placed between these soil layers as provided in Table 1. The test cell with the external dimensions of 50 × 50 × 50 cm³ is shown in Fig. 7. On the other hand, test results are given in Fig. 8, while bearing capacities in kPa unit corresponding to 10 mm settlement level are given in Table 3. In the present study, the scope was limited to monotonic loading conditions in order to evaluate bearing capacity at a defined settlement level. Incorporating unloading–reloading sequences is recognized as a valuable extension, and this aspect will be considered in future investigations.

Figure 7. Experiment cell and instrumentations.

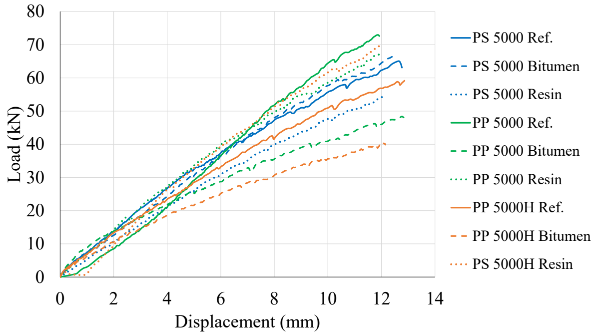

Figure 8. Plate load test results.

Table 3. Bearing capacities corresponding to 10 mm settlement (kPa).

	PS 5000	PP 5000	PP 5000 H
Reference	725.26	839.77	661.6
Bitumen	750.7	534.4	462.3
Resin	619.22	760.2	835.53

4.2.3 Puncture (tearing) test

Perforation issues may occur in geotextile materials due to sudden loads during the application. Typically, damage or puncturing occurs when aggregates or other materials fall onto the geotextile layer. In this study, a test apparatus compatible to ASTM D6241 was developed to evaluate the puncture resistance of both reference and coated geotextiles.

In addition to the damaged geotextiles retrieved from the plate loading tests, reference geotextile specimens measuring 30cm×30cm were prepared specifically for puncture tests. During testing operation, LVDT, load cell, and hydraulic piston were used to measure the applied loads and deformations, simultaneously. To ensure consistent test execution, the geotextiles were securely clamped between components of the apparatus, preventing slippage under load. The results for a total of 18 geotextile samples, and test apparatus are presented in Fig. 9 and Table 4.

Figure 9. Tearing test apparatus.

Table 4. Tearing test results before and after the tear test.

	Load (kgf)		
	Reference	**Resin**	**Bitumen**
PP 5000 Undisturbed	702.66	611.01	658.53
PP 5000 Disturbed	614.4	539.72	655.14
PS 5000 Undisturbed	526.15	370	736.61
PS 5000 Disturbed	461.65	349.63	706.06
PP 5000 H Undisturbed	577.06	553.3	760.37
PP 5000 H Disturbed	560.09	424.31	736.61

5 CONCLUSION

This study investigates the enhancement of the mechanical performance of geotextiles by the way of impregnation with bitumen and synthetic resin in terms of their load-bearing capacity between soil layers, puncture resistance, and tensile strength. For this, three types of geotextiles were evaluated using plate loading tests, puncture tests, and tensile strength test.

According to the test results, the highest impregnation rates of bitumen (1821.4 g/m²) and resin (4280.3 g/m²) were observed in the PP 5000 H type geotextile. In the plate loading test results, while no significant increase in bearing capacity was observed for PS 5000 and PP 5000 geotextiles, the PP 5000 H sample showed a 43.11% decrease and a 20.82% increase at the 10 mm settlement level compared to the reference value for bitumen and resin, respectively. Moreover, the PP 5000 H sample exhibited the lowest deformation levels among all types. In the geotextile puncture-tear resistance tests, the reference sample of PP 5000 showed the best resistance to tearing. Similarly, among the resin-coated samples, PP 5000 again demonstrated the best performance. In contrast, for the bitumen-coated samples, the best result was observed in the PP 5000 H type geotextile.

Overall, the bitumen-coated geotextiles exhibited the most favorable tensile performance, whereas the resin-coated geotextiles showed lower strain values due to their more brittle like behavior.

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