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Full Length Research Paper

In-situ modification of a road material using a special polymer

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The quality of materials used in road infrastructure and the grain size distribution of the materials are very important for road construction works. In many projects, appropriate road materials cannot be found easily around the project area and this increases the cost of projects. In this study, polymer was used as an additive for the improvement of a base material for road infrastructure. Working in the framework of a divided road in Keşan Uzunköprü (20th km), polymer was implemented in 100-m section at 1% of the dry weight of soil. Plate loading tests and field CBR tests were conducted on both of polymer; improved base and natural base without additive, and comparisons were made. In the plate loading tests, the maximum deformation decrease from 3.8 - 1.7 mm and permanent deformation decrease from 2.1 - 1.1 mm with polymer additive under very high stresses such as 1 MPa. Sieve analysis results showed that polymer binds and agglomerates the finer particles in the material and the finer content in the material drops from 7 - 1% with polymer. These types of improvements will allow the use of formerly unsuitable material in road construction works.

Key words: Polymer composites, soil stabilization, plate loading test, polymer, road.

INTRODUCTION

In road infrastructure projects, the quality of the filling material and its grain distribution are very important. If the appropriate filling material cannot be found in areas close to the construction site, then very high prices have to be paid in this type of road construction process, which causes significant delays or cost increases. In such cases, sometimes work with low-quality materials affects the road quality and durability over time and results in very significant losses. Improving the quality of materials is very important for road construction works, in order to ensure that projects meet the necessary cost and quality criteria. If road infrastructure material found close to the construction site does not meet the specifications, the materials can be improved with suitable chemicals such as lime, cement and fly ash etc. All the additives may be advantageous to certain type of materials. Polymers are large molecules or macromolecule composed of repeating structural units typically connected by covalent chemical bonds. Polymerization is the process of combining many small molecules known as monomers into a covalently bonded chain. Polymer-nano particles/ nano composites have been an exponentially growing field of research for materials-development in the last few decades and have been mainly focusing on the structure–property relationships and their developments (Kumar, 2009).

Nowadays numerous types of polymers are used for various purposes across a wide range of engineering applications. The use of polymers in construction activities has been increasing rapidly over time. In civil engineering, especially in polymer-fiber concrete, geotextiles and geogrids are increasingly used. The polymers were also used in waterproofing systems of building basements to control the groundwater leakage. For example, Al-Bahar (2005) examined the performance of selected polymer-based membranes for waterproofing

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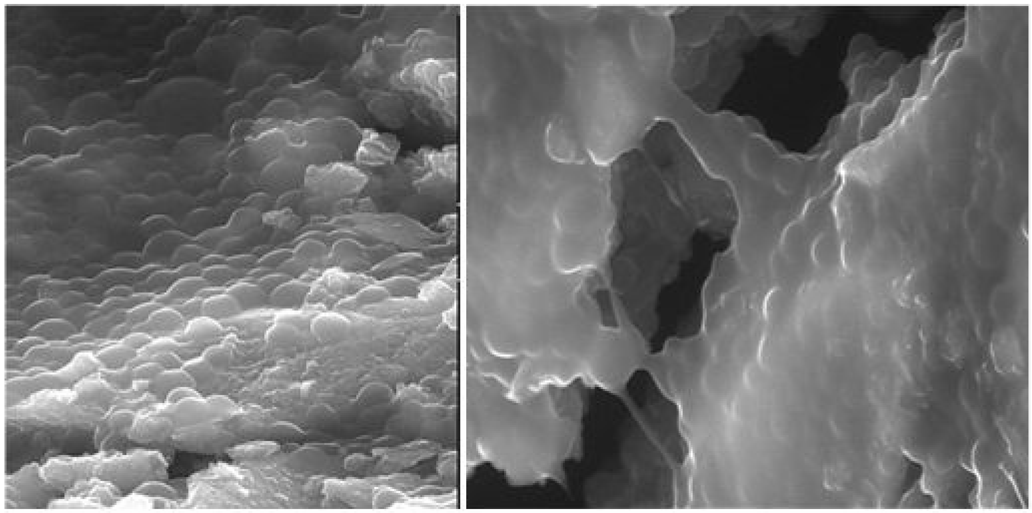

Figure 1. Scanning electron micrographs showing film formation over the surface of silica particles.

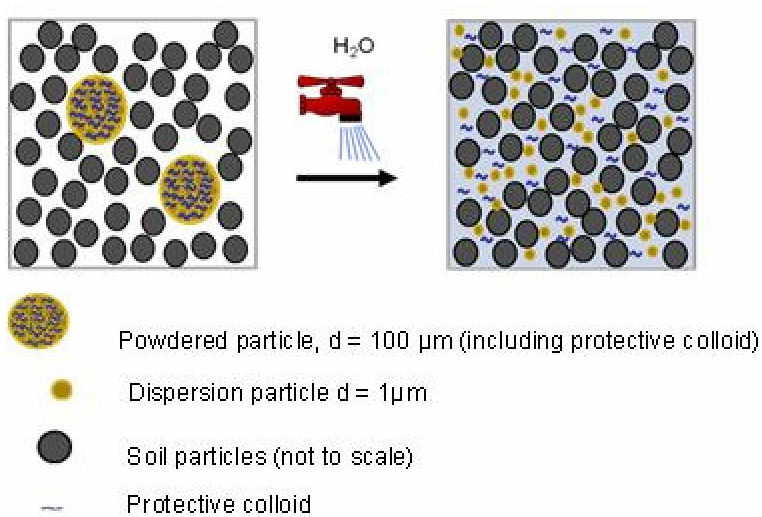

Figure 2. Upon addition of water, polymer powders were redispersed into their original dispersion particles.

building basements under continuous exposure to moisture, in which in actual service conditions, were evaluated. Although there are intensive uses of polymers in many branches, the use of polymers in road construction materials as additives is very limited. In some projects in USA and Europe, polymers have been used in liquid form to prevent dust in the summer months in order to ensure comfortable working conditions (Surdahl et al., 1989). Miller et al. (1998) have examined the effects of polymer in aggregate that contains kaolin type clay. In their study, the results of sieve analysis of certain sizes were observed and growing of soil grains were also observed after using polymers. Liu et al. (2009) studied the improvements in stability of a granular soil using two kinds of polymers. They showed the development in strength of soil materials using experimental and observational manner. Inyang et al. (2007) examined the swelling properties of bentonite clay using aqueous polymer and polymer additives, and an effective contribution to stabilization was noted. Figure 1 shows a scanning electron micrograph (SEM) image of polymer film formation over the surface of silica particles.

Polymers are not currently used in stabilizing highway construction materials. The present study reports on the use of a specially produced polymer, which is Wacker polymer modifier Etonis (R) 930, for a road material to make a soil polymer composite. The polymer is in a powder form and after the addition of water, the powders redispersed into their original dispersion particles. The process and the definitions of the components are shown in Figure 2.

The protective colloids do not only help to redisperse

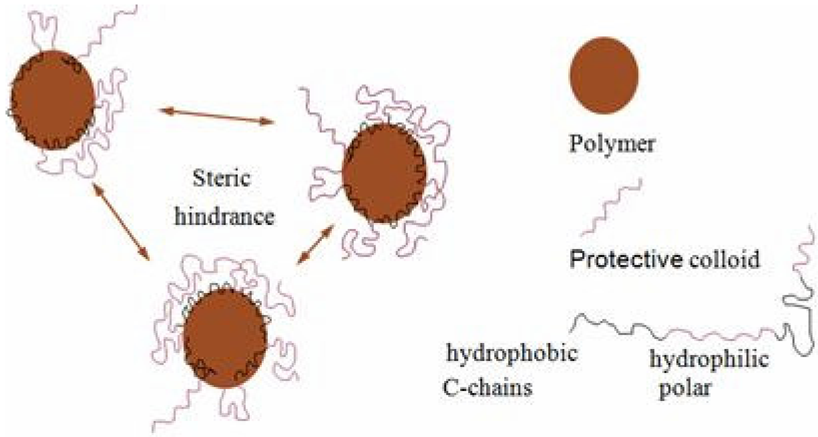

Figure 3. Independent polymer solids in the dispersed phase.

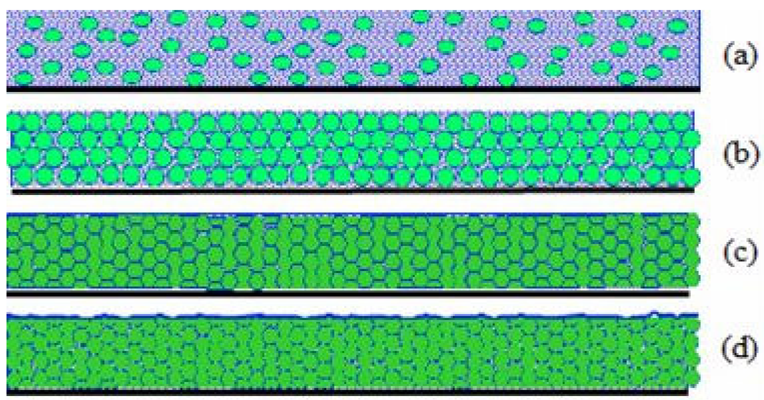

Figure 4. a) Dispersion with individual polymer particle; b) Evaporation: Particles converge; c) At the end of evaporation process: Deformation of particles; d) Formation of a homogeneous film by interdiffusion of the particles.

polymer powders, but also they keep the polymer particles separated as independent polymer solids in dispersed phase. The typical polymers and protective colloids, hydrophobic C-chains and hydrophilic polar are shown in Figure 3.

The film forming process of polymers starts by dispersing individual polymer particle. After evaporation, particles converge and deforms. A homogeneous film was formed by interdiffusion of the particles. Film forming depends on monomer base, Tg (Glass transition temperature) of polymer and also on the presence of plasticizers and film forming agents. The film forming process of polymer is shown in Figure 4.

The dispersible powders reveal their structure in SEM (Scanning electron microscopy) in Figure 5.

Working in the framework of a divided road in Keşan Uzunköprü (20th km), polymer was implemented in 100-m section. A similar field experimental methodology was followed to that defined by Kavak and Akyarli (2007) for improvement by lime stabilization *in-situ* application. Plate loading tests PLT and California bearing ratio CBR field tests were conducted over base layer, in both sides with or without polymer, and comparisons were made to observe the effect of polymer in road material performance. A crushed stone base material that satisfies the necessary criteria was used for the defined road construction work. Polymer was added to this material in order to observe a potential changes in material characteristics. This type of additive has the potential to increase the strength and durability of road construction materials, thereby reducing construction and maintenance costs.

MATERIALS AND METHODS

Methodology

The objective of this research was to determine the effectiveness and performance over time of polymer additives on a real divided road project in Turkey. The polymer additive was implemented on a

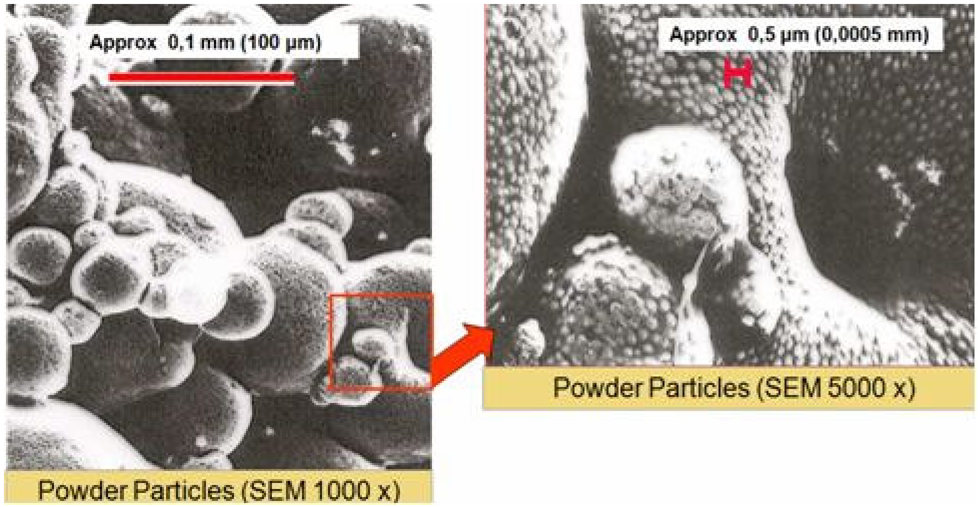

Figure 5. Scanning electron microscopy on polymer dispersible powders reveal their structure.

100-m long road section in Keşan-Uzunköprü (20th km). This road was in a scope of highway divided road project of the highway department of Turkey. The polymer was added in powder form to the base material at the quarry during production stage. The materials with polymer additive were then taken by trucks to the construction site. The material was placed and compacted at predetermined thickness, which is 20 cm by compacting at the optimum moisture content in the construction site. The amount of polymer used was 1% by dry weight the soil. The road segment adjacent to the additive applied area was also constructed using the same base material, without polymer additive, but with the same compaction effort for comparison.

The relative compaction values and water content values of the compacted soil at the site were determined by a nuclear Troxler gauge. Confirmation tests were conducted using sand cone method and moisture content determination in an oven at a temperature 105°C. *In-situ* PLT and field CBR tests were conducted to observe the performance of the polymer additive on the road performance just after the application, after 10 days and 6 months. The tests were conducted both on the natural base material and on the base material with polymer additive. Grain size analysis, Modified Proctor tests and soaked *CBR* tests were conducted in the laboratory, for both of natural samples and the same soil samples mixed with the polymer.

Materials

Geotechnical properties of base material were examined in the laboratory according to modified Proctor, sieve analysis, liquid limit, plastic limit and soaked CBR tests. Tests were conducted in accordance with ASTM D1557-78, ASTM D421&422, ASTM D4318 and ASTM D1883-87 standards (Bowles, 1992). Atterberg limit tests results showed that the material was non-plastic *(NP)* as expected, since the base material is produced from crushed stone. Grain size analyses with polymer were conducted with samples taken from the constructed road. The ranges of the basic geotechnical test results of natural base material with and without polymer were summarized in Table 1.

Granular base material consists of 83.4% gravel, 9.6% sand and 7% fine material. From Table 1, it can be seen that the fines content (clay+silt) decreased from 7% to around 1% by polymer additive. The addition of polymer changes the grain size distribution of the material by binding the fines particles, leading to agglomeration of the smaller soil particles. According to the unified soil classification system, the addition of polymer changes the base material from silty gravel (GM) to poorly graded gravel (GP) and well graded gravel (GW). Both of the materials were classified as A-1-a according to the AASHTO soil classification system. The dry unit weight of the materials decreases from 20.8 - 19.2 kN/m^3 and the optimum moisture content also decreases from 5.1 - 4.4% with the polymer additive (Figure 6)

Soaked CBR values are doubled compare to natural soil specimens. Sieve analyses were conducted in a laboratory and grain size analysis of the material were determined. The Sieve analysis tests were conducted in accordance with ASTM D 421 and D422 standards (Bowles, 1992) and the results are shown Figure 7.

Polymer as defined agglomerates the soil particle, if the soil particles dimensions are less than 7 mm as shown in Figure 1. The amount of fine material is an important problem for quarry materials. Fine material content, which are more than the defined, decreases the strength.

RESULTS AND DISCUSSION

Plate loading tests

Plate loading tests were conducted in the field in order to compare the performance of natural material and the polymer-added material. The tests were conducted again after 10 days and 6 months in order to determine the effect of polymer on the road material characteristics over time. Plate loading tests were carried out with a 30 cm diameter steel plate. The deformation readings were made with 3 different deformation gauges and the average deformation value was used to draw the graphs. The load was applied with a dual-cell jack and the pressures were recorded during the test. The forces acting on the plate were calculated using the previous calibrations of the hydraulic jack. All the tests were conducted with a maximum value of 1 MPa stress, in order to allow comparison between test results for each case. After application of loading and unloading, the

Table 1. Geotechnical properties of natural base material and base material with polymer.

	GP nature. material	GP with polymer
Soil classification		
Soil definition - USCS	GM	GP-GW
Soil definition - AASHTO	A-1-a	A-1-a
Thickness limits (%)		
PL	N.P	N.P
LL	N.L	N.L
PI	N.P	N.P
Sieve analysis - USCS		
Gravel (76.2 - 2 mm) (%)	83.4	81.7 - 94.9
Sand (2 mm - 0.074) (%)	9.6	3.4 - 18.2
Silt and Clay (< 0.074) (%)	7.0	0.7 - 1.7
Soaked CBR (polymer 10 days)	60	114
Field CBR tests		
CBR Value (%) (Polymer cured 10 days)	85	106
Compaction parameters		
M.K.B.H.A. – Modified proctor (kN/m^3)	20.8	19.2
Optimum water content (%) - Modified proctor	5.1	4.4

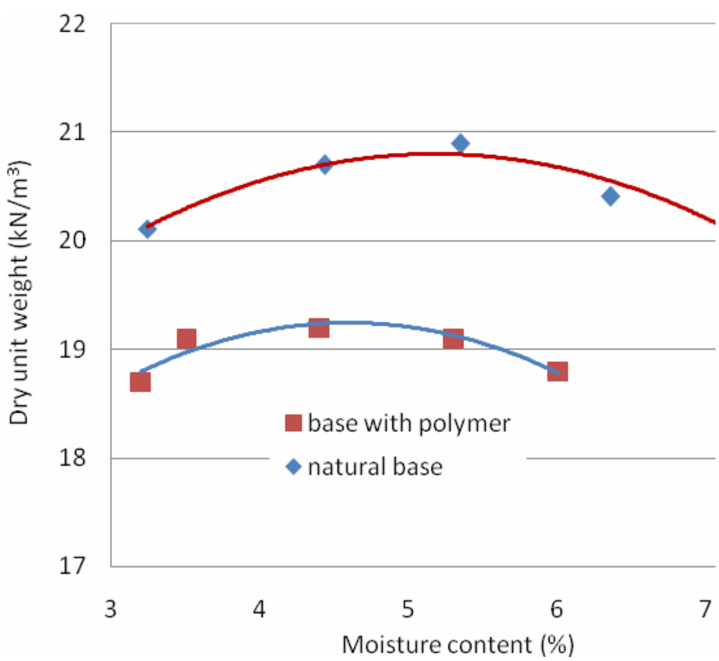

Figure 6. Modified proctor tests.

maximum (S_{max}) and permanent deformations ($S_{perm.}$) in the soil were recorded and the stress-deformation graph was drawn. Stress-deformation graphs of PLT tests conducted on the base and subbase layers without polymer are shown in Figure 8.

In-situ relative compaction values were determined, using a nuclear Troxler gauge, and the results were also checked by sand cone tests. It was found that the relative

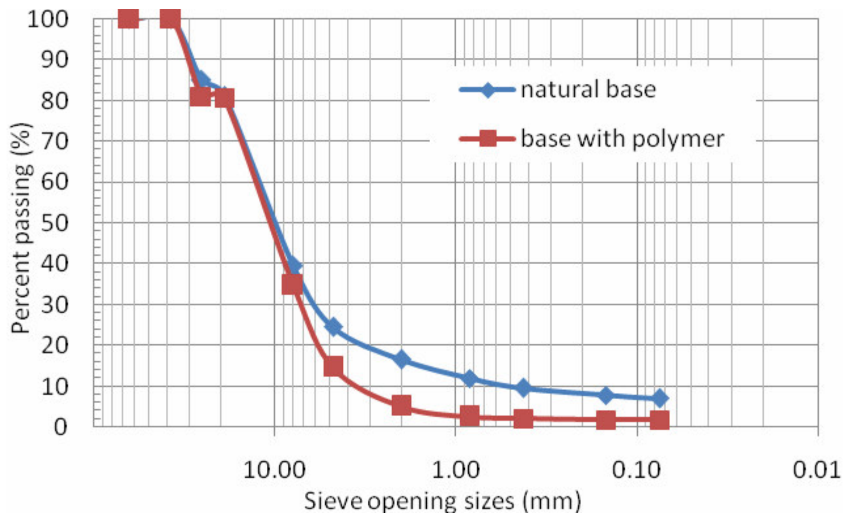

Figure 7. Grain size analysis of base material and base material with polymer.

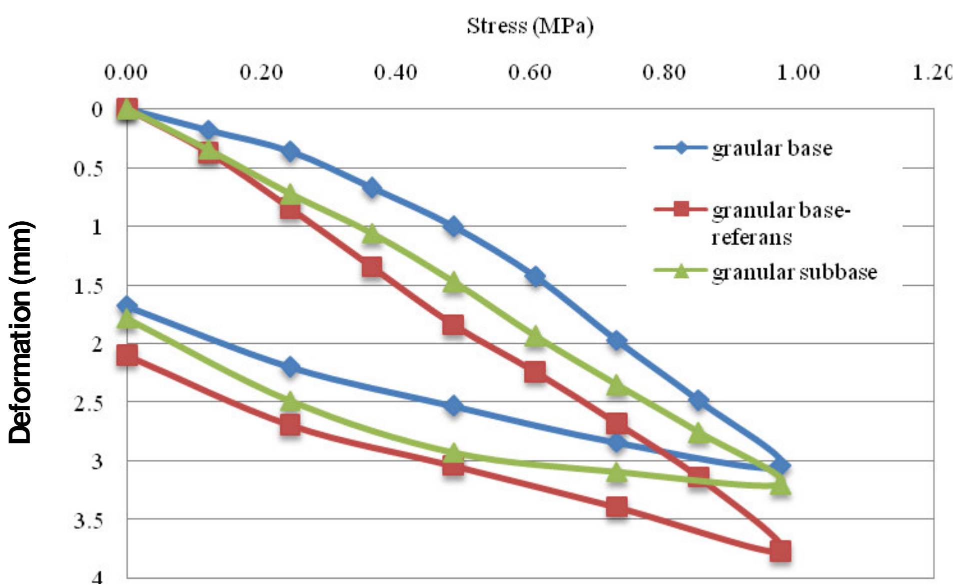

Figure 8. Plate loading tests conducted on base and subbase layers of the road.

compaction values were within the range 96.2 - 98.2%, while water content values were between 2.6 - 5.7%. The *PLT* test at 5.7% water content was applied on a granular base layer constructed at the same construction time with that of polymer additive. Other two tests were conducted on natural materials previously constructed; these two sections had been previously constructed, and so their water content was lower than the optimum value. The modulus of subgrade reaction of the road base was calculated by using tangents at 1.25 mm deformation from the loading parts of the stress deformation graphs (DIN 18134, 2001). It was found that modulus of subgrade reaction *(k)* values were found between 29000 and 68000 kN/m^3. Data summaries plate loading tests applied on base and sub-base materials in the field are show in Table 2.

From Table 2, it is clearly seen that drying was observed in the materials except the base material at 5.7% water content. The reason was that two tests were conducted on the previously constructed areas, but the granular base at 5.7% water content was constructed and compacted at the same time as the polymer applications. Since the drying increases the strength, the results of *PLT* tests with polymer in Figure 9 were compared with the case of natural granular base constructed at the same time with polymer applications. After construction

Table 2. Plate loading tests and relative density determinations summary on base and sub-base layers.

	w (%)	kN/m³	Before application			
			Rel. comp. (%)	S_{max} (mm)	$S_{perm.}$ (mm)	k(kN/m³)
Granular base material	4.5	20.5	98.2	3.1	1.7	68000
Granular base material	5.7	20.5	98.2	3.8	2.1	29000
Granular sub-base material	2.6	20.1	96.2	3.2	1.8	35000

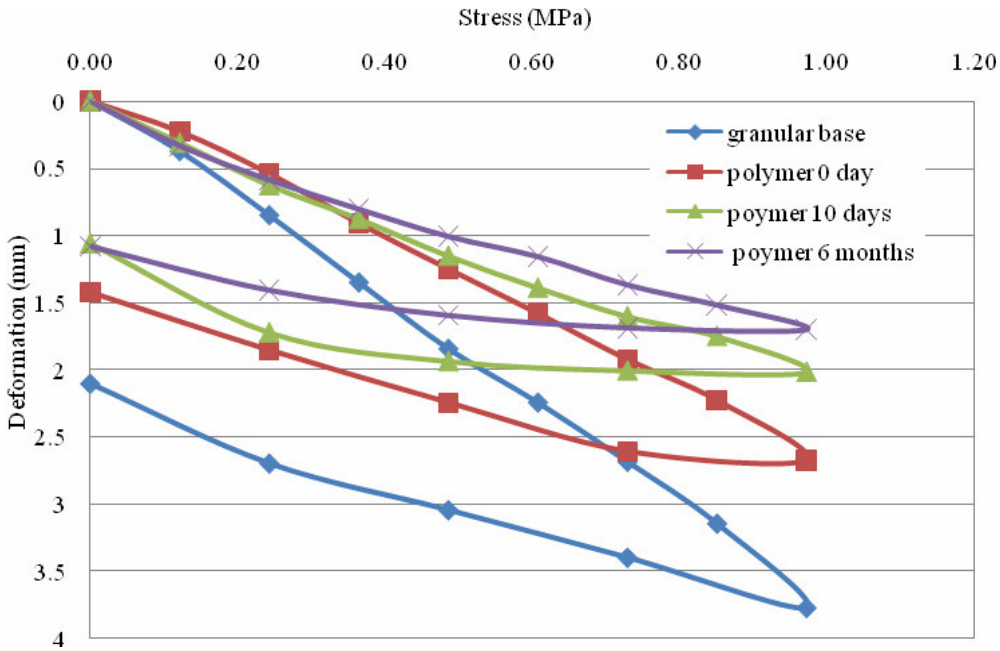

Figure 9. Time-series comparison of plate loading tests conducted on base material and base layer with polymer additive.

Table 3. Summary of plate loading tests and relative density of base layers with polymer additive.

	w (%)	kN/m³	After-application.			
			Rel. Comp. (%)	S_{max}(mm)	$S_{perm.}$(mm)	k(kN/m³)
Base-with-polymer 0 day	3.4	19.2	99.8	2.7	1.4	49840
Base-with-polymer 10 days	3.5	19.3	100.3	2.0	1.1	39620
Base-with-polymer 6 months	3.6	19.2	99.8	1.7	1.1	53300

and compaction applications of base layer of the road with and without polymer additive in the field, the *PLT* tests were conducted immediately after the application, for 10 days and 6 months after the application, on the three polymer-applied points and one non-applied point (Kavak et al., 2009) (Figure 9).

Comparison of the plate loading test results for the natural and polymer-added materials indicated that, although the polymer-base is not covered with a surface coating, it showed less permanent and maximum deformations compared to the natural material. Even after a relatively short period (10 days) and under high loads (1 MPa), the effect of the polymer can be clearly seen in the graphs, and improvement continued at the6 months. The data are summarized in Table 3.

At 6 months, the maximum deformations during loading *(S_{max})* decreased from 3.8 mm in the natural material to 1.7 mm with polymer (Table 2). The permanent deformation *($S_{permanent}$)* values were also reduced from 2.1 mm in the natural samples to 1.1 mm with polymer. It was found that the relative compaction values were within the range 99.8 - 100.3%, while water content change ranged from 3.4 - 3.6%. Moduli of subgrade reaction *(k)* values were found to range from 39620 - 53300 kN/m³. No

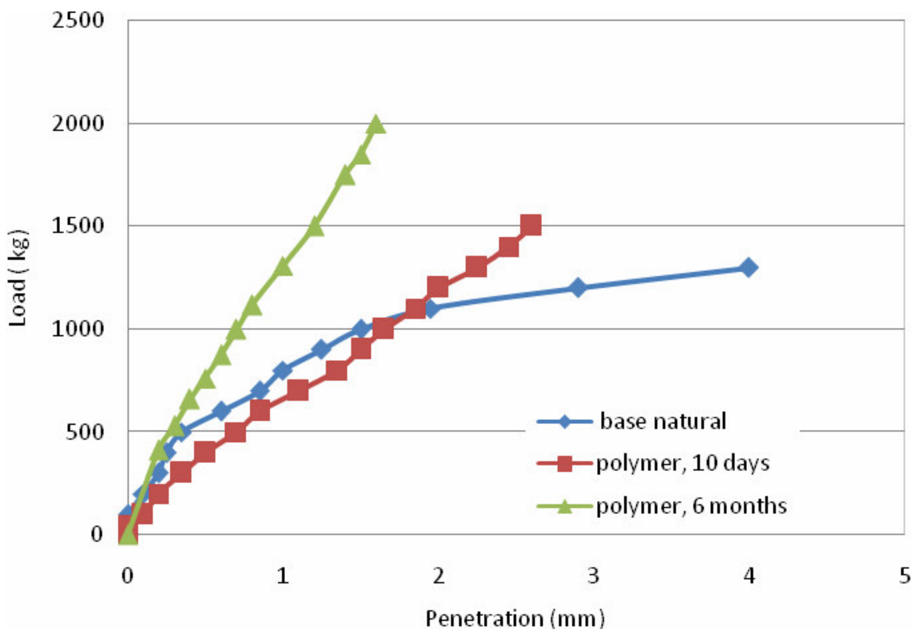

Figure 10. Comparison of Field CBR test results.

significant changes were observed in modulus of subgrade reactions. This is because, while compressing the elastic behavior of the material, no considerable changes were thus observed.

CBR tests

The CBR test is currently used in pavement design for both of roads and airfields. Some Departments of Transportation use the CBR directly. Others convert the CBR value to either to modulus of subgrade reaction k or to Resilient Modulus using empirical relationships. CBR tests can be conducted on the field as field CBR and also in the lab dry or soaked CBR tests. The road design soaked CBR tests are used in many places as defined.

CBR tests that were conducted in the field on polymer-mixed base and natural base are shown in Figure 10. It can be seen that field CBR test values have an increase on the polymer-mixed state and this continues with time.

For the CBR tests conducted for 6 months, the deformation could not get up to 2.5 mm penetration, which is necessary for CBR calculation, since the strength of the improved soil is very high. During the test, since load capacity of the field CBR apparatus was exceeded, CBR value is defined as > 150. Swelling during the soaking process was found as zero for both of the materials since the soil was a granular one. Figure 11 shows CBR values in the field and soaked CBR values in the laboratory. CBR tests conducted in the laboratory are also very important to the properties of the material. For 10 days, the soaked CBR values with polymer reached 114, when compared with 60 for an initial natural granular material.

The increases in soaked CBR values are very important for filling material characteristics, as construction specifications include many limitations, related specifically to soaked CBR values. An unsuitable material can therefore, be made suitable with higher CBR values. Another important point is the thicknesses of fill layers; increased soaked CBR values will allow the use of thinner fill layers, thus resulting in cost reduction for road construction projects.

The natural soaked CBR value increases from 60 - 114 with polymer additive. In road infrastructure works, soil with a CBR value of 100 can be used in all layers below asphalt. The use of polymer in the present study increased the soil's CBR value approximately 2 times and the material can be transformed from non-suitable base material to a suitable one for high quality road constructions works. These kinds of improvements will provide significant economic benefits while it reduces the environmental impact of such projects.

Conclusions

The polymer additive results demonstrate that using polymer in granular road materials can improve the soil's engineering properties and provide significant contributions to road infrastructure projects. The results indicate that addition of 1% polymer by dry weight results in improved geotechnical characteristics in the field applications and create a polymer soil composite. The strength of crushed stone base material used for road infrastructure was increased after the addition of polymer,

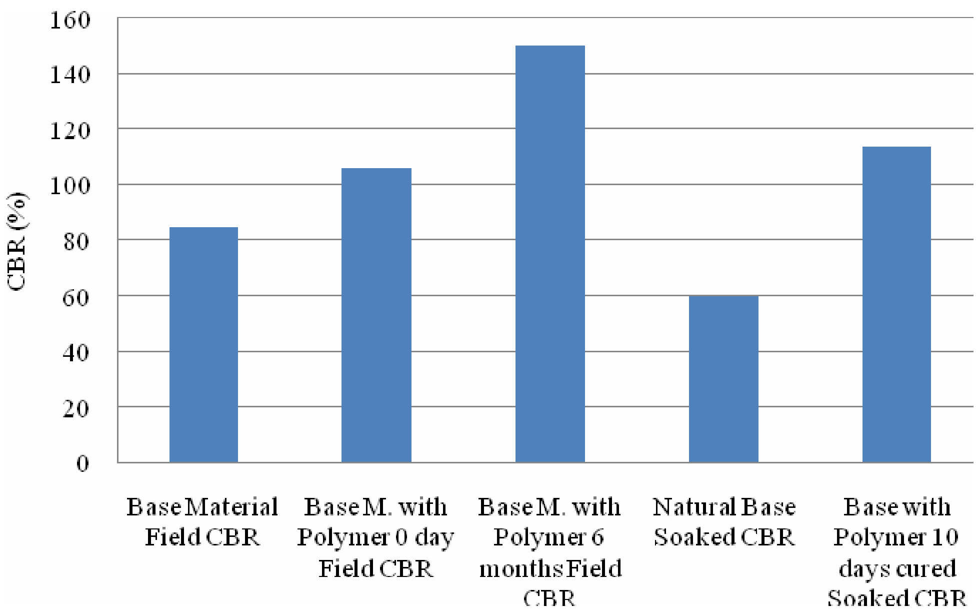

Figure 11. Field CBR and laboratory soaked CBR results.

while deformations of the road surface were reduced. In plate loading tests in the field, under 1 MPa stress, the maximum deformations decrease from 3.8 - 1.7 mm and permanent deformation decrease from 2.1 - 1.1 mm. Additives like these could be used generally for improving the specifications of low quality materials, and can also result in reduced layer thicknesses in projects where higher *CBR* values are specified.

After examining the sieve analysis results, it was seen that the addition of polymer caused the soil to become more granular by binding the fine particles to each other. In the test, the fines content (clay+silt percent) was reduced from 7% to approximately 1%. This change can allow previously, unsuitable filling materials to be used in road infrastructure by reducing the proportion of the finer content, especially in low quality materials.

These kinds of studies are still at very early stages, both in Turkey and around the world. However, based on the characteristics of polymers identified in the present study, polymers may be used effectively as an additive for soil stabilization in road infrastructure, in addition to their use in polymer-fiber concrete, geogrids and geotextiles in Civil engineering applications. The use of polymers to improve the geotechnical properties of soils allows the use of lower quality materials that may be available closer to the project site, and thus its use in filing works will become common. Similarly, the potential reduction in the need for quarried materials will help conserve natural resources. The use of on-site or nearby materials in filings, will significantly reduce transportation costs and provide both economic and environmental benefits

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