The Effects of a Hot Dry Climate on the Strength of Geotextiles and Geogrids

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ABSTRACT: A study has been undertaken in Kuwait to investigate the effects on the strength of geotextiles and geogrids of exposure, storage and burial in soil in a hot dry climate. Kuwait was chosen as it experiences air temperatures ranging from 45°C in summer to 0°C in winter and has an extremely high UV radiation level with long hours of uninterrupted sunshine most days of the year. Comparative evaluations of the effects of long term exposure, storage and burial in soil on the strength of two geotextiles and two geogrids were carried out. These indicate quite different responses from the four products, ranging from total degradation of the woven geotextile to virtually no measured effect on the strength of the uniaxial geogrid. The data also indicate that short and long term strength testing methods do not necessarily provide the same evaluations of the response of products to temperature cycling and UV radiation.

1 INTRODUCTION

The aim of the study was to investigate the effects of the hot dry climate of Kuwait on the strength of two geotextiles and two geogrids which were subjected to prolonged exposure, storage out of sunlight and burial in soil at 0.5 and 1.5 m. The test location chosen was the College of Technological Studies in Shuwaikh at which the soil and environmental conditions are typical of the majority of mainland Kuwait.

Both Index and Performance strength tests were performed on the exposed, stored and buried samples of four types of geosynthetics which were representative of those most commonly adopted for separation and reinforcement applications in Kuwait. Samples of each type were tested before and after 3, 6 and 12 months environmental conditioning. A fully detailed account of this work is given by Al-Mudhaf (1993).

2 PROPERTIES OF THE SOILS AT THE SITE

The soils investigation was conducted at 16 points over the site to a maximum depth of 4m. Samples were carefully selected to represent the vertical and horizontal variations in soil properties. These investigations showed that the soil on the site was non-plastic fine to medium sand with very little coarse sand and a coefficient of uniformity (C_u) ranging between 1.8 and 2.5. No evidence of a water table was found down to a depth of 4 m. The water content increased with increasing depth, ranging from less than 2% at a depth of 0.25 m to just over 12% at 1.5 m. The values were determined on a dry winter day (15 December 1991). In-situ density measurements indicated that the average in-situ dry unit weight of the soil was 12.5 kN/m^3 which represents a relative compaction of about 70% compared to the Proctor maximum dry unit weight. Chemical analysis of soil indicated that the Chloride content in the soil as 'Cl', ranged between 0.007 and 0.176%, the Sulphate content as SO_4 content, ranged between 1.0 and 4.1% and the amount of SO_3 ranged between 0.9 and 1.47%. The Organic matter content in the soil ranging between 0.003 and 0.056% and pH values were 7.5 to 8.5.

3 UV RADIATION AND TEMPERATURES

The test set-up for air and soil temperature measurements comprised one temperature sensor located in a shaded housing above ground and a group of sensors embedded at 0.5, 1 and 1.5 m in the soil at the site. A Pyranometer was used to measure solar radiation. The recorded variations in air temperatures indicated a maximum of 49°C (summer) and a minimum of 4°C in winter. Soil temperatures at 0.5m were 40°C (summer) and 12°C (winter) with daily variations of 1 to 3°C. At 1.5m into the soil the maximum was 35°C, the minimum 21°C with daily variations of 1 to 2°C. The cumulative UV radiation over the 12 months of the study was measured as 1,800,000 wh/m^2. The rate of radiation in the summer was twice that in the winter.

4 TYPES OF GEOSYNTHETICS USED

Four kinds of geosynthetics were used in this study, a polypropylene woven geotextile (Lotrak 35/30), a polypropylene/polyester needle punched geotextile (Netlon 601-S), a polypropylene biaxial geogrid (Tensar SS-1) and a high density polyethylene uniaxial geogrid (Tensar SR-80). The reasons for choosing these particular materials were that they represented the range of materials available in Kuwait and that they represented different physical structures and polymers. Samples of each type of geotextile and geogrid were cut from undamaged rolls provided by the manufacturers. The first two turns of each roll were discarded and not used for sampling. Samples 1m (MD) x 4m (XMD) were cut, these being sufficient to obtain all the required test specimens for each situation. All samples were checked to ensure they did not contain any irregular spots, holes or any other damage.

5 SITE AND LABORATORY TEST PROGRAMME

One sample of each type of material was tested immediately on delivery from the manufacturer. This testing obtained the basic "Control" set of data for the full range of tests.

Four samples of each type were set out vertically on the test site and left open to all weathering conditions including direct sunlight. These were called "Exposed" samples and were removed for testing after 3, 6 and 12 months. The same test procedures were applied to test these samples as were used for the Control samples. Some further samples were exposed and tested after exposure during the periods of 3 to 6 months and 6 to 12 months to provide additional data.

Four samples of each type of material were kept in an opened sided wooden room, where they were subjected to all weathering conditions except direct sunlight. They were called "Storage" samples and were removed after 3, 6 and 12 months for testing. The same test procedures were applied to these samples as were used for the Control samples.

Samples of each type of material were buried in the soil, four at a depth of 0.5 m from ground level and four at a depth of 1.5m, each in a separate excavation. These were called "Buried in soil" samples. They were removed at the same times as the storage samples and the same procedures were adopted for their testing.

Test specimens were cut from the material samples in accordance with ISO/DIS 9862 (1990). The Index testing was carried out at the University of Strathclyde and the sustained load (creep) tests were carried out in Kuwait. The tests were carried out in accordance with the test methods detailed in Table 1.

Table 1 Test methods employed

Test	Method
Puncture Resistance	BS6906, Part 4 (1988)
Cone Drop	BS6906, Part 6 (1989)
Tear	ISO TC.38/SC (1990)
Wide Width Tensile	BS6906, Part 1 (1987)
Wide Width Creep	Andrawes et al (1986)

6 INDEX TEST RESULTS

Puncture, cone drop and tear tests were carried out on the two geotextiles. Wide width tensile tests were carried out on the geotextiles and the geogrids. The data resulting from this Index test programme showed the following:

6.1 Puncture Test Data

(a) Effects of exposure: The woven geotextile suffered an almost complete loss of puncture resistance and became very brittle following exposure to solar radiation of 1,000,000 wh/m^2. The puncture force for the non-woven geotextile was hardly affected but the displacement reduced by 25% after 12 months.

(b) Effects of storage: There was a 25% loss of puncture resistance and a slight decrease in displacement for the woven geotextile after 12 months. The non-woven showed little change in puncture force but a 25% decrease in displacement to puncture over the same period.

(c) Effects of embedding in soil: There were no significant changes in the puncture resistance of the woven geotextile due to burial but there was a 15% decrease in the displacement of the non-woven geotextile after 12 months.

6.2 Cone Drop Test Data

(a) Effects of exposure: For the woven geotextile the cone penetration increased rapidly to complete penetration beyond 1,000,000 wh/m^2 radiation. For the non-woven geotextile there was a 20% increase in the cone penetration after 12 months.

(b) Effects of storage: There was a 10% decrease in cone penetration for the woven and a 20% increase for the non-woven after 12 months.

(c) Effects of embedding in soil: Cone penetration decreased by some 20% for the woven and increased by 20% for the non-woven after 12 months.

6.3 Tear Test Data

(a) Effects of exposure: For the woven geotextile the tear force rapidly decreased to almost zero after 1,000,000 wh/m^2 radiation, with an associated decrease in displacement. After 12 months the non-woven geotextile showed a 20% reduction in tearing force and a 60% decrease in the displacement.

(b) Effects of storage: The woven geotextile showed losses of 50% of the tear force after 12 months. The displacement was similarly affected. For the non-woven geotextile, the tearing force reduced by 25% associated with a 60% decrease in displacement.

(c) Effects of embedding in soil: There were approximately 10% reductions in the tearing force and displacement of the woven geotextile after 12 months. There was also 10% or less reduction in the tearing force of the non-woven geotextile, but the displacement reduced by some 20% after the same period.

6.4 Tensile Test Data

6.4.1 Geotextiles

(a) Effects of exposure: For the woven geotextile the maximum and break loads in the MD direction, reduced to almost zero after exposure to 1,000,000 wh/m^2 radiation. In the XMD direction there were 60% reductions after 12 months with similar reductions in strains. After 12 months, the non-woven geotextile showed 10% reductions in maximum and break loads in the XMD direction but little change in the MD direction, however 30 to 40% reductions in strains were recorded.

(b) Effects of storage: The woven geotextile exhibited 30% reduction in the MD direction and 10% reduction in the XMD direction for both the maximum and break loads after 12 months storage and these were associated with similar decreases in strains. The non-woven geotextile also exhibited a 10% decrease in maximum and break loads in the XMD, and 30% reduction in strains in the MD and XMD directions.

(c) Effects of embedding in soil: The effects of burial on the woven geotextile were 5 to 10% reductions after 12 months. The XMD direction was again the more critically influenced. The non-woven was not significantly affected. There was a consistent 10 to 15% reduction in strains for all cases after 12 months in soil.

6.4.2 Geogrids

Both of the geogrids exhibited no decrease in tensile properties for any condition at any time, indeed they showed up to 5% increase in strength after burial in soil for 12 months.

6.5 Comparisons Between The Data Obtained From The Various Index Tests:

All the Index strength test methods showed consistent and related patterns of behaviour which added confidence to the individual test results. They also showed that measurement of displacements or strains, was as important as measurement of loads. In particular they showed that a material may not change its strength greatly, but may increase in brittleness, which is of great practical significance.

7 PERFORMANCE (CREEP) TEST DATA

Wide width sustained load (creep) tests were carried out on all four geosynthetics. The percentage loads used were 10, 20, 30 and 40% for the woven geotextile, 5, 10, 15 and 20% for the non-woven geotextile and 10, 20, 40 and 60% for both geogrids. The percentage loads referred to are percentages of the maximum Index tensile test loads per metre of the control test specimens for the various materials.

7.1 Woven Geotextile

(a) Failures of test specimens

For the control test specimens, the creep strain behaviour of the test specimen with 40% load exhibited a significant change from the other test specimens. Strain values reached 140%, and the test specimen failed at 600 hours loading time. In comparison, the strain values reached for the other control test specimens (at lower loads), ranged between 10 and 50% at 1,000 hours.

For the exposed test specimens, two failures were recorded at 30% and 40% loads for specimens exposed for 6 months, approximately 800,000 wh/m^2 radiation. Failure occurred in the first 20 hours of loading. All exposed test specimens exposed for 12 months failed in the first few seconds of loading.

For the storage test specimens, after 6 months storage, the test specimens at 40% load failed after only 16 hours. For the test specimens stored for 12 months, failure occurred at 40% load after 500 hours.

For test specimens buried in soil at 0.5m, the creep behaviour of the test specimens was generally unchanged. No failure was reported, with all test specimens sustaining 1,000 hours loading. The exception to this was that a change in behaviour was noticed for 40% loading. The maximum strain at 1,000 hours was 119% which is lower than for the control test specimen.

For test specimens buried in soil at 1.5m for 3 months, a failure occurred for the test specimen loaded to 40%. This failure occurred at 500 hours loading time (100 hours earlier than the failure of the control specimen). A further sample failure occurred after 210 hours for the test specimen at 40% load which had been buried in the soil at 1.5 m depth for 6 months.

All of the above failures consistently occurred through the middle of the test specimens, confirming that the test procedures were effective.

(b) Amount of creep strain at 10 s and 1000 hrs

The amounts of creep strain in the very short term (10 s) and after 1000 hrs for the woven test specimens which had been subjected to the various environments compared to the behaviour of the control test specimens showed that the behaviour of the woven geotextile was critically affected at or close to 40% loading. This confirms the previous data on failures and suggests that this woven geotextile should not be subjected to sustained loads approaching this level in any circumstance.

(c) Effects on the stiffness at different strain levels

The effects of being subjected to different periods of the various environments, identified in terms of the stiffnesses of the woven geotextile test specimens relative to the control test specimens show that the test specimens subjected to the various environments were stiffer than the control test specimens. However, it is clear that the effects on the stiffness varied with the strain level, with the greatest effects being at 1% strain and the least at 10% strain. That the influence of environmental effects under operational conditions is related to operational strain levels is an important finding.

7.2 Non-woven Geotextile

(a) Failure of test specimens

No failure was recorded for any test specimens, but the loads applied were restricted to a maximum of 20%.

(b) Amount of creep strain at 10 s and 1000 hrs

This geotextile suffered very large strains in the first few seconds of loading then strained very slowly thereafter. This was due to the very loose initial structure of the non-woven geotextile. The effect of being subjected to the various environments compared to the control test specimens was to significantly reduce the strains at all times, i.e. both in the very short term (10 s) and after 1000 hrs. It may be suggested that this was to some extent due to silt and sand in the structure of the materials restricting the mobility of the fibres forming the geotextile although some changes in the fibres themselves may have taken place.

(c) Effects on the stiffness at different strain levels

The effects of being subjected to different periods of the various environments were identified in terms of the stiffnesses of the non-woven geotextile test specimens relative to the control test specimens and show that the specimens subjected to the various environments were much stiffer than the control test specimens. Further, that over the strain range 10 to 20% for the various periods in the different environments, these changes were consistent. Thus the changes occurred at low strains and after very short loading periods. Therefore, it is likely that these effects are more related to changes in the mobility of the fibres induced by the presence of silt and sand in the structure, than to changes in the fibres themselves, confirming what was stated previously. This is an important finding in relation to their operational behaviour. To a large extent it confirms the need for in-soil testing of non-woven geotextiles as previously suggested by McGown et al (1982). This type of testing takes account of the reduced mobility of fibres in non-woven geotextiles when confined by soil.

7.3 Biaxial Geogrid

(a) Failures of test specimens

A number of the environmentally conditioned test specimens subjected to 60% load failed. The very high levels of recorded strains at failure, from 38 to 54%, are important with respect to the application of this material in civil engineering, in so far as they occur at strains far in excess of the usable strain range recommended by the manufacturer, Netlon (1984).

(b) Amount of creep strain at 10 s and 1000 hrs

The amounts of creep strain in the very short term (10 s) and after 1000 hrs for the biaxial geogrid test specimens which had been subjected to the various environments were compared to the behaviour of the control test specimens. These data showed that in the very short term, (10 s), there were some decreases in creep strain but not consistently, suggesting that the variations were perhaps due to sample variability. In the longer term (1000 hrs) there was again a scatter of data with, however, more evidence of decreased strains in the exposed specimens.

(c) Effects on the stiffness at different strain levels

The effects of being conditioned for different periods in the various environments were identified in terms of the stiffness of the biaxial grid test specimens relative to the control test specimens. The data generally showed a slight tendency for the test specimens to increase their stiffness with respect to the control specimens under all conditions. Most variation occurred at low strains but overall the data suggest that the material was affected very little by environmental conditioning.

7.4 Uniaxial Geogrid

(a) Failures of test specimens

Two failures occurred at 60% loads. One occurred after 500 hrs for a specimen which had been buried at 0.5 m for 3 months and the other after 800 hours for a specimen which had been buried at 1.5 m for 6 months. The failure strains recorded were 14.3 and 14.5%, respectively. No other specimens strained to these levels, which are greatly in excess of the maximum usable strain of 10 per cent recommended by the manufacturer. Failures at this level of strain and loading have previously been reported on "Control" specimens by Yeo (1985) so that it is unlikely that the failures were induced by the environmental conditioning. Also the failures occurred in the ribs, which confirmed the findings of Yeo (1985) and the test procedures adopted in this study.

(b) Amount of creep strain at 10 s and 1000 hrs.

The amounts of creep strain in the very short term (10 s) and after 1000 hrs for the uniaxial grid test specimens which had been subjected to the various environments were compared to the behaviour of the control test specimens and showed that the behaviour of the uniaxial grid was not critically affected by environmental conditioning. Only for the 3 month Exposure test specimens at very short term loading (10 s) were any changes noted. These changes were likely to have been more to do with sample variability than environmental conditioning.

(c) Effects on the stiffness at different strain levels

The effects of being subjected to different periods of the various environments were identified in terms of the stiffness of the uniaxial grid test specimens relative to the control test specimens. This showed that the test specimens subjected to the various environments changed little compared to the control test specimens, most specimens showing variations within the degree of accuracy of the data.

7.5 Comparisons Between The Data Obtained From The Various Creep Tests

The data from the sustained load (creep) tests clearly identified the differences in behaviour between the four materials studied. The woven geotextile was shown to creep significantly, its behaviour controlled by the nature of the polypropylene from which it is manufactured. The behaviour of the needle punched non-woven was shown to be initially dominated by its loose structure. Only after the structure had "tightened-up" did creep of the fibres contribute to the overall strains. The behaviours of both the geogrids were controlled by the nature of the polymers and the processing methods used for their manufacture. The uniaxial geogrid exhibited much less strain and more regular behaviour than the biaxial geogrid.

The differences between the woven geotextile and the biaxial geogrid, both consisting of polypropylene, were indicative of the differences in processing of the polymer, the biaxial grid having been drawn to a higher extent than that in the woven product, making it more crystalline. It is very difficult to establish exactly what additives, (and in what quantities), have been used in each product thus it was not possible to quantify their effects.

The reactions of the four materials studied to the environmental conditions were also very different. The thin woven geotextile suffered most severely. Possibly this was due to two basic reasons; the first is that it had by far the greatest exposed surface area to volume of all of the materials and the second, that it consisted of polypropylene of relatively low crystallinity. The non-woven material possessed a high fibre surface area to volume ratio but many of the fibres were not on the outer faces of the material. The fibres in the centre of the product were protected to some degree from radiation and heat cycling effects. Further the fibres were individually stressed to a much lower level than those of the woven product during the testing. Both the geogrids comprised components of much greater thickness than the fibres of the geotextiles and were much more crystalline which features were beneficial to their behaviours.

8 COMPARISONS BETWEEN THE INDEX AND PERFORMANCE (CREEP) TEST DATA

Many of the previous studies related to the durability of geosynthetics have depended upon Index tests to quantify the effects of environmental conditioning. In this study, perhaps uniquely, both Index and Performance strength tests have been conducted on geosynthetics before and after environmental conditioning so that the ability of the different test methods to detect loss of long term performance may be identified.

As a mean of assessing the data, Al-Mudhaf (1993) calculated ratios of the values of the properties of the environmentally conditioned specimens over the control specimen values. This was done for all the measured Index properties and for the creep test 1000hrs isochronous secant stiffnesses at 1, 5 and 10% strain for the woven geotextile and the two geogrids, together with the isochronous stiffnesses at 10, 15 and 20% strain for the non-woven geotextile.

On the bases of these assessments it was found that there was a lack of good correlations between any of the Index test data and the sustained load (creep) test data for the geotextiles. This is a very important finding so far as durability testing of geotextiles is concerned. Without doubt the Index tests did provide very good data on puncturing, tearing and perforation and on the short term tensile strengths. However, it would appear that the Index tests do not reflect very closely the long-term load-strain behaviour of the geotextiles. Only for the geogrids were good correlations found to exist between the Index and Performance test data, however, it must be pointed out that the geogrids did not suffer significant changes in properties due to environmental conditioning, therefore there were no real changes in either sets of data. Thus it appears that creep testing is required as has been recommended previously by Rankilor (1989).

9 CONCLUSIONS

a) Comparitive evaluations of the strengths of two geotextiles and two geogrids exposed, stored and buried in soil for up to 12 months in the hot dry climate of Kuwait, indicated quite different responses from the four products. These ranged from total degradation to virtually no measured effects.

b) Exposure of the products was the most severe of the conditions, comprising UV radiation of some 1,800,000 wh/m^2 after 12 months together with severe temperature cycling on both a daily and seasonal basis.

c) Perhaps surprisingly, storage was the next most severe condition. This reflects the severe heat cycling to which the stored products were subjected in Kuwait.

d) Burial in the soil of Kuwait did not prove to be a critical condition. This reflects the dry, inert nature of the soil and much lower levels of heat cycling than for exposure and storage.

e) The Index testing adopted proved to be a consistent means of determining the degradation of the products studied in terms of the properties tested. Further they showed that measurement of deformations, (or strains) , was as important as measurement of loads in order to detect degradation effects.

f) Only poor correlations were found between the degradation effects measured by the Index tests and those measured by performance (creep) tests.

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