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Testing environmental stress cracking of high density polyethylene

J.-M.Jailloux
Terre Armée Internationale, France

P.L.Anderson
The Reinforced Earth Company, USA

ABSTRACT: Due to the lack of information on high density polyethylene (HDPE) geogrid durability characteristics, especially those related to crack initiation and propagation, Terre Armée Internationale has decided in 1991 to perform a set of tests in order to evaluate the real performance of HDPE geogrids. The results reflect clearly that HDPE geogrid products which contain nonoriented or weakly oriented material appear to retain their well-known susceptibility to stress cracking. Because of the presence of a "knee" in the log of applied stress - log of time to failure relationship, extrapolating data from the first linear portion will produce significant errors regarding time to failure.

1 INTRODUCTION

This testing program was conducted to provide data that describes the stress rupture characteristics of HDPE material used in a popular geogrid product.

Very little, if any, notched stress rupture has been performed on HDPE geogrids. The pioneering nature of the testing program has produced exciting and interesting results. This testing program was sponsored by the Reinforced Earth Company, McLean, Virginia, and performed by GeoSyntec Consultants' Materials Testing Laboratory, Boyton Beach, Florida.

2 THE HDPE GEOGRID PRODUCT

The geogrid product consists of high density polyethylene material which is highly oriented (with respect to its molecular arrangement) in the rib area, but to a much lesser extent in the node area. The differences in orientation are due to the geogrid manufacturing process which involves :

. punching rows of holes in thick, extruded sheet ;

. stretching the heated, softened sheet to form elongated material (ribs) separated by elongated, parallel holes ; and

. cooling the resulting grid in this stressed condition.

This manufacturing process makes the ribs stronger than the nodes, but only in the direction of orientation.

3 STRESS CRACKING

Stress cracking is the brittle fracturing of thermoplastic material under sustained stress at a significantly lower stress than the material's yield strength.

In this geogrid testing program the stress crack resistance is assessed by determining the time to failure at several stress levels.

In notched stress rupture testing, a notch helps to induce plane strain conditions and to provide a defined zone of stress concentration. The plane strain conditions are initiated and persist during craze extension, because the material surrounding the notch, being less stressed than the material in the notch, prevents lateral shrinkage of, and stress distribution in, the notch area. As a result, crazes propagate along a plane which extends away from the root of the notch.

4 TESTING PROCEDURE

The testing procedure used for determining the stress rupture properties of the geogrid is outlined in the Geosynthetic Research Institute (GRI) standard GM-5. The test parameters, with the applicable GM-5 sections referenced in parentheses, are as follows :

. 1 % Igepal Solution (8., Condition A);
. 30 % Notch Depth (9.2);
. 50° C, 65° C, 80° C (9.5);

Two types of specimen were used (Figure 1):

. Type 1 Specimen - notch in rib ; and
. Type 2 Specimen - notch in transition zone.

Notches were cut by pressing a razor blade (in a perpendicular motion) into the selected surface of the geogrid specimen. All notches were cut to a controlled depth equal to 30% of the geogrid's thickness in that location. Thirty percent of the original thickness is the maximum allowed by GM-5 and was selected for practical reasons involving the specimen loading requirements.

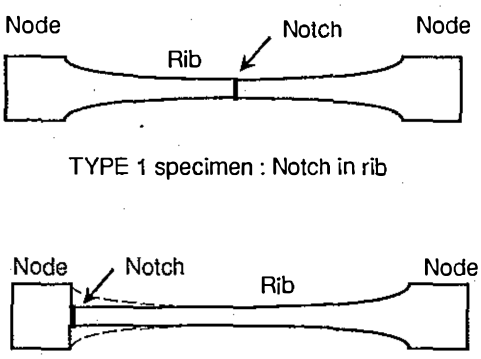

Fig.1 Configurations of the notched specimens

In the preparation of Type 2 specimens, some of the lateral transition material (being of non uniform cross-sectional thickness) was carefully excised with a razor to create a rectangular cross section. The rectangular cross-section provided for reproducable testing results that could be achieved practically and economically.

Testing stresses were generally selected to produce failure times ranging between 0.001 hr and 1000 hrs. The stress applied to each specimen was based upon the applied load and the cross-sectional area at the test notch. The stress calculations, however, do not make any adjustments for stress concentrations (notch factor), which are not known in terms sufficiently accurate to use them in the calculations. This is not considered a particularly significant deficiency in the methodology, However it does increase the need for uniformity of specimen preparation and testing.

5 RESULTS

Table 1 summarizes the locations of all observed failures in notched specimens as affected by notch location, testing temperature, and applied stress.

Table 1. Locations of failures

Type	Notch location	Temp. (°C)	Stress (MPa)	Failure Location
1	Rib	80	76	at notch in rib
1	Rib	80	69 - 24	in node (away from notch)
2	Transit. zone	80	38 - 22	at notch in transition zone
2	Transit. zone	65	40 - 22	at notch in transition zone
2	Transit. zone	50	47 - 22	at notch in transition zone

Data from all testing series are compiled in a single figure (figure 2). The representation needs to be in a log-log scale in order to reveal the linear correlation between log of stress applied and log of time to failure.

Examination of the results revealed the following :

. Stress rupture properties were affected by temperature .
. Type 1 specimen data plotted higher than Type 2 specimen data clearly showing a higher material strength for the rib material than for the transition zone.

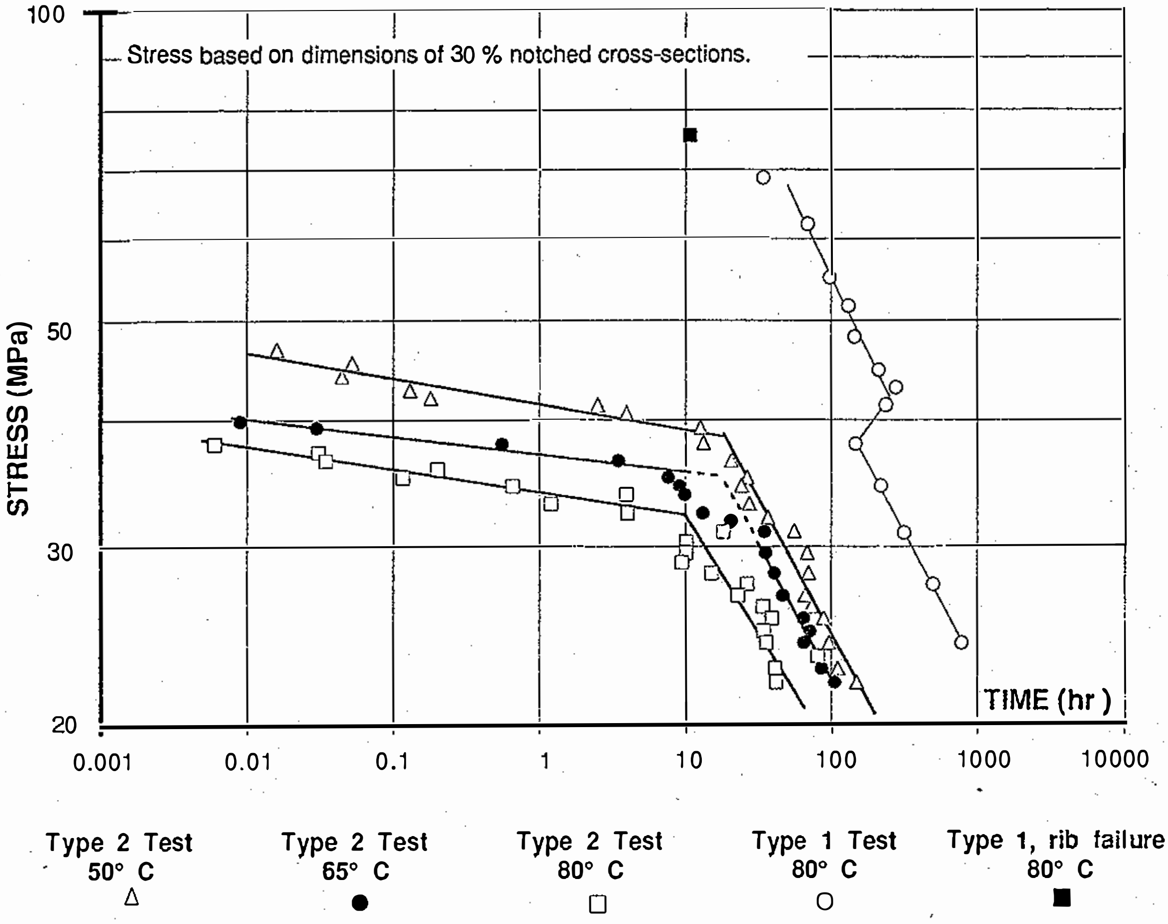

Fig.2 Results of notched stress rupture testing of HDPE geogrid at 50, 65, and 80 °C in 1% Igepal.

6 COMMENTS RELATED TO TYPE 1 SPECIMENS

It is important to point out that, with the exception of the 76 MPa point, the tests on Type 1 specimens do not provide quantitative information for the following reasons:

1. failures were not induced at the notched location used for calculation of applied stress
2. stress imposed at the actual failure location cannot be estimated accurately due to the use of loading hooks through holes in the node; and
3. inconsistent rupture patterns occurred in the node material.

Nevertheless, since the node is much thicker and wider than the notched rib, stresses in the failed node material were much lower than stresses in the notched rib material. A downward shift of the plotted data would reflect this; however, the amount of downward shift cannot be determined for the above reasons.

Microscopic examination showed that Type 1 specimens failed in a number of ways. The following are the three important observations:

- The failures were by brittle cracking in the node.
- The fracture faces of failed specimens were similar to those of HDPE sheet material (i.e., material with little orientation) tested under similar conditions.
- Fracture faces exhibited increasing smoothness with decreasing stress, indicating decreasing ductility. This trend is consistent with experience with sheet materials and is widely documented.

7 COMMENTS RELATED TO TYPE 2 SPECIMENS

In contrast with Type 1 specimens, Type 2 specimens produced consistent results at the three temperatures.

Type 2 specimen failures led to a number of significant observations:

- For any given stress level, time to failure (life) of Type 2 specimens increased with decreasing temperature.
- The three Type 2 specimen curves corresponding to equal 15°C increments, appeared to be equally spaced.
- All Type 2 specimen curves (figure 2) consisted of two linear portions with different slopes meeting to form a "knee". In this respect, moderately oriented material in the geogrid transition zones has a behavior similar to nonoriented material (e.g., sheets).
- Because of the presence of a knee in the curve, extrapolating data from the first linear portion (i.e., the portion before the knee) will produce significant errors regarding time to failure.
- There was no evidence of brittle cracking in the transition zone material.
- In all cases, plastic deformation occurred across the notch.
- Total plastic deformation decreased at higher stresses.
- The elongated material was considerably more fibrous in specimens tested at lower stress (below the knee of the stress-rupture plot) than in specimens tested at higher stresses (above the knee). This fibrous nature in the elongated material was manifested by clumps of loosened fibers and by rupture, apparently in shear, along planes running parallel to the direction of fiber alignment.

The plastic deformations observed in Type 2 specimens appear to have resulted from a combination of:

. plastic deformation primarily due to creep in the transition zone material; and

. cold drawing of material from adjacent node material.

These two processes progressed simultaneously, each to a greater or lesser extent, until the lengthened fibers ruptured at relatively low elongations.

8 CONCLUSIONS

This program generated data which should help to quantify effects of molecular orientation on the engineering properties of HDPE geogrids.

The manufacturing processes of HDPE geogrids appear to induce more molecular orientation in the ribs than in the junctions. This research program shows that HDPE material with differing degrees of molecular orientation will have variable resistance to stress cracking. As a result, HDPE geogrids are more susceptible to stress cracking in the junctions than in the ribs. The increased resistance to stress cracking normal to fiber orientation is accomplished, however, at the expense of strength in the nonoriented direction(s), which predisposes oriented material to "splintering"-type failure (along planes parallel to oriented fibers).

Thus, the overall performance of HDPE geogrids is governed by the weakest portion of their constitutive materials. Since the behavior of nonoriented material does not follow a constant regime and presents discontinuity in the course of time it is anticipated that the product will be affected accordingly.

GeoSyntec Consultants and The Reinforced Earth Company have agreed that additional testing is required to investigate the following issues :

- the range of temperatures that have an influence on notched stress rupture properties and the time to ductile-brittle transitions in partially oriented material;
- whether or not water, in the absence of surfactant, plays a significant role in initiating and propagating stress cracking in geogrids; and
- whether or not notches are needed to initiate stress cracking in geogrids in an environment which is otherwise conducive to its occurrence.