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Investigation of stress cracking in a reinforced polypropylene floating cover

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ABSTRACT: A post-tensioned reinforced polypropylene floating cover on a reservoir began to crack after about 6 years of service. Cracking occurred in the exposed green surface layer but did not occur in the underside white layer, even where it was stressed and exposed around the periphery. Cracking occurred on the slopes but not on the water. Laboratory testing found the synergism of UV radiation and stress caused a rapid reduction in the high pressure oxidation induction time (HP-OIT), but a less significant reduction for oven aging under stress.

1 INTRODUCTION

A cut and fill reservoir was built on the downwind slope (wind rising upslope) in a valley. A 1.5 mm thick green (up)/white (down) post-tensioned reinforced PP floating cover was installed. During operation there were constant problems with the fold of excess material on the upper slopes lifting and flapping in strong winds, and the cover above the fold on the slopes uplifting. Significant abrasion was occurring on the cover by the tensioning wires. The tensioning wires were raised, but this only resulted in increased lifting forces on the fold and increasing exposure to the wind. A ballast strip was placed on the cover above the fold but the uplift problem was never satisfactorily resolved.

Figure 1. Cracking in dark area on slope.

2 OBSERVATIONS

After about 6 years the cover started cracking, primarily on the slopes, and predominantly on the upwind side of the reservoir where the inside slope was in the lee of the wind (Figure 1). At some locations the excess material was neatly folded (Figure 2) but at others the tensioning wire had pulled away from the pulley at the base of the tensioning post and was lifting the fold (Figure 3) towards the top of the post, increasing the tensions and exposing the cover to wind. The cracks were generally in the darker areas on the exposed part of the fold as shown in Figure 1.

Figure 2. Tidy fold of excess cover material.

The cracks were initiated on the warp (roll direction) reinforcing yarns up and down the slopes (Figure 4) and at 45° to the slopes in corners (Figure 5). Thus, the initial cracks were not perpendicular to the expected primary stress direction, up and down the slopes.

Figure 3. Cover tensioned directly to top of post rather than via pulley at base of post.

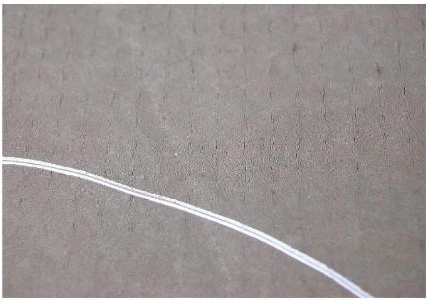

Figure 4. Cracks initiating on warp yarns up and down the side slope.

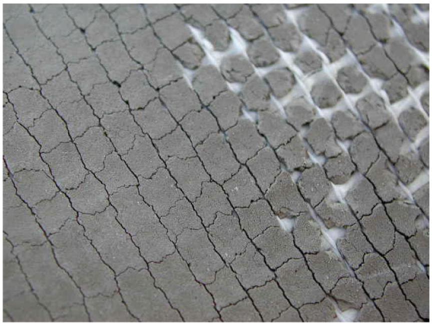

Figure 5. Major cracks on warp yarns (top left to bottom right) at 45° to slope and minor cracks on weft yarns (bottom left to top right), with PP layer beginning to spall.

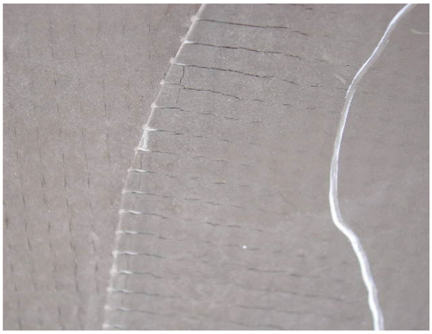

Figure 6. Cracking on cover (left) and patch (right).

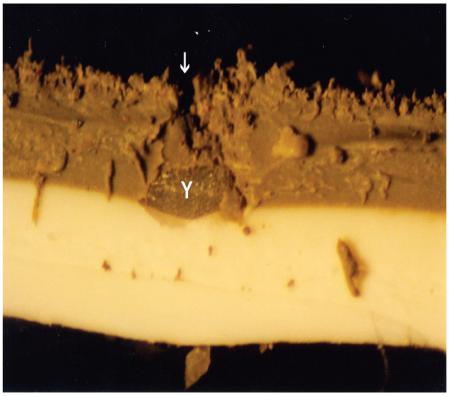

Figure 7. Crack (arrowed) above round warp yarn (Y).

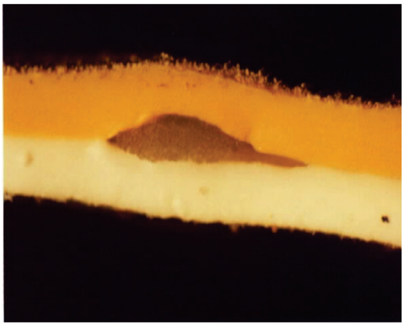

Figure 8. Elliptical weft yarn.

Cracking along the weft yarns subsequently occurred (Figure 5), then the resulting small squares of exposed PP began to spall off the liner. At one interesting location cracks occurred normal to one another in the cover and a patch (Figure 6).

There was essentially no cracking in the cover in contact with the water at lower stresses and lower temperatures. Microsections of the cover showed the warp yarns to be round in cross section (Figure 7) while the weft yarns were more elliptical with the longer axis in the plane of the sheet (Figure 8). Therefore, the bending stresses of the PP polymer over the warp yarns were higher, hence the first failures at these locations.

At another site and in another RPP product the complete exposed layer was removed (Peggs, 2005). Cracking was most advanced in the higher temperature stressed areas, but only occurred in the exposed green layer. There were no cracks in the underside white layer, even where it was exposed and tightly bent around a securing line outside the peripheral batten strip, as shown in Figure 9.

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Figure 9. Stressed white layer exposed to UV radiation.

Samples were removed from archive material and from various sections of the cover for high pressure oxidative induction time (HP-OIT) measurements. Results are shown in Table 1.

Table 1. Laboratory HP-OIT test results.

Material	HP-OIT (min)
Archive white	556
Archive green	133
White	302
Lighter green	99
Darker green	53
Cracked green	15

It was clear that both layers had lost some oxidation resistance, the green more so. The cracked material had effectively lost all resistance.

Specimens of unexposed archive material were subjected to GRI.GM18 Oven Aging and UV Resistance tests both with and without stress, approximately 1 MPa (147 psi). Specimens were cut on the bias so only the polymer layers would take the stress. Only the green layer was exposed to UV radiation. After only 500 hr of the 1600 hr UV test exposure the stressed specimen was found to have cracked in the green layer (Figures 10 and 11) with

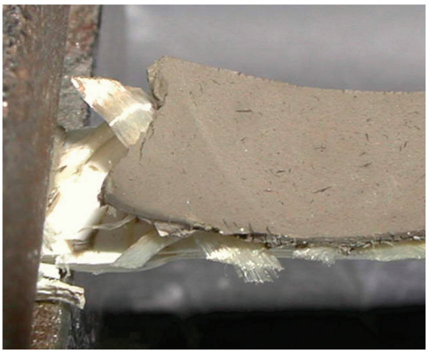

Figure 10. Cracked constant load UV specimen. Break at jaws in upper green layer only on warp yarn. Note "flat" weft yarn.

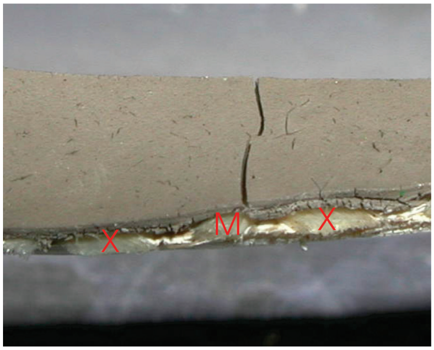

Figure 11. Major crack above round warp yarn (M) only. Smaller cracks on surface. Flatter weft yarns X.

Table 2. HP-OIT of lab stressed/exposed green material.

	Unstressed	Stressed
Archive HP-OIT (min)	133	133
Thermal aged (min)	130	62
OIT retained (%)	98	47
GRI-GM18 spec (%)	50	–
UV exposed (min)	102	<1
OIT retained (%)	77	0
GRI-GM18 spec (%)	60	–

the same features as in the field. Pre and post test HP-OITs are shown in Table 2.

After the test its retained HP-OIT value was effectively zero, while that of the unstressed specimen was 77%. The oven aging unstressed and stressed specimens had retained HP-OITs of 98% and 47% respectively. Thus the synergism of both thermal and UV aging with stress is clearly evident, with stress having a more significant effect on UV degradation.

While a stress is needed for crack initiation and propagation it is possible that strain in a PP geomembrane opens up the microstructure which results in an increase in the rate of inward diffusion of oxidizing agents into the microstructure. This accelerates the leaching and consumption of protective additives. Small cracks and fissures formed in the surface open up more surface area to degradation by UV radiation. An acceleration in thermo- and photo-conductive aging in PP under stress has also been observed by Czerny (1972).

It is, therefore, necessary to re-think durability specifications for PP geomembranes. These specifications must include the effects of stress (strain) on the kinetics of oxidation and photodegradative processes. As a consequence of these and similar failures in other applications of unreinforced and reinforced PP geomembranes the GRI.GM18 standard has been provisionally withdrawn as GRI performs research to establish more appropriate durability specifications. In the interim, and based on the present test results, it may be relevant to consider the following durability parameters:

- UV resistance (GRI.GM18) under a constant stress of 1 MPa. No break and HP-OIT retained > 75%
- Oven aging (GRI.GM18) under a constant stress of 1 MPa. No break and HP-OIT retained > 75%

It would probably also be wise to perform a chemical resistance test under the same constant stress at 50°C for up to 90 days and to examine the surface for cracks and to measure retained HP-OIT compared to reference specimens tested under the same conditions but in air. Unfortunately no acceptance criteria can be suggested for this test, due to a lack of research. And the UV and oven aging criteria should in no way be considered to guarantee performance. They are simply a guide until additional data are developed that will lead to more supportable values. Undoubtedly they will be the subject of much discussion, which is the intent of presenting them.

3 CONCLUSIONS

Cracking in the floating cover occurred due to a combination of stress, temperature and UV exposure. Durability specifications for PP geomembranes must include parameters for stress/UV exposure and stress/thermal oxidation. The former is more critical.

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