Practical Guidance on Specifying GCL Overlaps to Account for Shrinkage[i]

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This article provides preliminary recommendations for developing project-specific specifications related to the amount of GCL overlap required to compensate for potential panel shrinkage. These recommendations are based on an ongoing laboratory investigation that has been developed to replicate observed field conditions where GCL shrinkage has occurred. Although these results are preliminary, it was felt that publishing these recommendations at this time is appropriate given the seriousness of the concern.

Background

Although shrinkage of unreinforced GCL panels in the field has been acknowledged and managed for many years, the awareness of panel shrinkage of reinforced GCL products is very recent. The first published acknowledgement of this issue for reinforced products was by Thiel and Richardson (2005) which mentioned five incidences of GCL panel shrinkage that had been discovered in the fast few years. All the cases involved reinforced GCLs that had initially been overlapped 6 inches, and then were covered with a geomembrane which was left exposed for extended periods of time on the order of two months to five years. For various reasons, the owners of these facilities had to cut open or remove parts of the geomembrane, at which time they discovered that the GCL panels had shrunk in the widthwise direction anywhere from 10 inches up to 3 or more feet. Gaps existed between the GCL panels where there had initially been overlaps. A photograph of one such example is shown in Photo 1. Thiel and Richardson (2005) surmised several possible reasons why the shrinkage could occur, without attributing the cause to any particular hypothesis.

In April 2005 the Geosynthetics Institute (GSI) published a white paper (Koerner and Koerner, 2005), describing their research and conclusions regarding the GCL shrinkage issue. This paper was later published in the June 2005 issue of GFR. They narrowed the plausible mechanisms that would lead to gaps on the GCL to three: (1) Shrinkage "perhaps accompanied by cyclic wetting and drying"; (2) longitudinal steep-slope tensioning; and (3) contraction on relatively flat surfaces. The white paper strongly emphasized the steep-slope tension-necking as the leading causative mechanism leading to GCL panel separation. For the one case in South America that experienced very large amounts of separation on a regular basis on relatively flat slopes, they conjectured that GCL "panel contraction" was caused by expansion and contraction of the overlying textured geomembrane, which may have "gathered" the GCL and caused it to bunch up.

Their recommendations for designers were as follows *[notes in italics by current authors]*:

1. Cover exposed GM/GCL installations with at least 12 in. of soil in a timely manner.
2. Do not use GCLs with needlepunched nonwoven geotextiles on both sides unless one of the geotextiles is scrim reinforced.
3. Increase the GCL overlap to compensate for the potential panel separation. With the exception of one California case, an increase of 4-12 inches *[above the standard 6 inches]* would have been adequate in the other cases. *[Actually, two out of the five cases experienced shrinkage gaps up to 3 feet.]*
4. Protect the exposed GM/GCL composite during its exposure time by using thermal blankets, geofoam, or other insulation techniques. *[The use of white-surfaced geomembrane is a very practical technique to help accomplish this.]*
5. Develop a NDT Method to Detect GCL Panel Separation.
6. Create full-scale field test sites to study the conditions under which GCL panel separation occurs. *[The authors are aware of two such ongoing field studies. Useful data from those studies may be available within the next year.]*

Wet-Dry Cycling

During the panel discussion at the GRI-Geofrontiers conference in February 2005, Greg Richardson stated his belief that the most likely cause of the GCL shrinkage phenomenon was due to cyclic hydration and drying of the GCL panels.

For very-high moisture content ($w_{initial}$ = 70%) non-reinforced GCLs, shrinkage by drying is not a new or surprising phenomenon. The authors' firm has experienced this while performing CQA on projects with these types of materials, where dramatic shrinkage would occur from the beginning of the day to the end, with complete loss of overlaps. This phenomenon was mention by Mackey (1997). Cautions also exist in the manufacturer's literature for these products, and thus shrinkage-by-drying for these types of products was previously recognized.

For reinforced GCLs, however, one drying cycle has not been observed to create such a problem. Certainly it has been verified by the current investigators, as well as the Geosynthetic Institute, that one cycle of drying, in both field and laboratory studies, would not result in shrinkage levels that are comparable to the case histories. Our laboratory studies indicate a maximum shrinkage of approximately 2% with one drying cycle, whereas the field-observed shrinkage was up to 10 times this amount. By the same token, it is not so critical whether or not the GCL picked up additional moisture through humidity or some other cause before installation. Again, one cycle does not make a large impact on shrinkage.

Cyclic wetting and drying, however, can have a profound impact on GCL shrinkage, as demonstrated by the laboratory testing described later in this paper, and could fully account for the observed field case histories. How could the GCL go through wetting and drying cycles in the field? This is very plausible. Remember that the situation we are discussing is a GM/GCL installation that is left exposed with no soil cover. During the daytime, the exposed geomembrane will increase in temperature due to the sun. This increase in temperature has been measured up to nearly 70°C on black geomembranes (Wellington and Daniel, 1995; Cadwallader et al., 1993), and would be the driving force for drying the GCL and underlying subgrade during the day. During the evening, when temperatures cool down and there is no sun, the vaporized moisture that is trapped below the geomembrane will condense into droplets. If there is an appreciable slope, the moisture may run downhill and gather at the toe, forming a water pillow. If there is only a slight slope, then the water would be available to go back into the GCL. At the same time that this is occuring, the natural matric-suction of the bentonite in the GCL will always have a tendency to draw moisture from the subgrade. The rate at which a GCL will draw moisture from the subgrade will be site specific, and depend on the subgrade moisture conditions and matric-suction characteristics of the soils. Thus, we have a mechanism for hydration/drying cycles of exposed GM/GCL installations. The magnitude of wetting and drying would be expected to vary substantially at different sites, different exposures (e.g. south vs north facing slope), from day-to-day, week-to-week, and season-to-season.

Tension-Necking

As mentioned previously, the GSI white paper strongly emphasized tension-necking as the leading causative mechanism to explain the observed GCL panel separation. While this mechanism does not apply to the case on the relatively flat slope, the GSI authors postulate that this could be a large contributing factor to situations on slopes. The GSI laboratory testing certainly indicates that any tension induced in the products will exacerbate potential necking problems. They also found that the amount of necking will vary between different products.

While the necking phenomenon caused by tension is certainly a real and measurable cause and effect, at least two of the five cases were not suspected to have tension in the GCL. On the other hand, tension-necking was surmised to be the leading causative mechanism for panel separation at the Badlands project in California which had very steep slopes, approaching 1.5[H]:1[V]. The authors have also observed some downdrag of an unrestrained GCL on a 2:1 slope that appeared to be caused by the diurnal expansion and contraction of the overlying textured geomembrane, which suggests that this could be a potential mechanism for creating tension had the GCL been anchored at the top.

There were some direct field measurements and observations made by the CQA monitor in the Virginia case described by Thiel and Richardson (2005) that suggest tension-necking was not a factor for that project. In that case, which was on a 3:1 slope, we can first of all take note that the whole reason that the GCL panel separation was discovered was because the geomembrane had to be replaced due to the <u>lack</u> of “Velcro” effect. The type of geomembrane that was supplied for that project had a low-profile calendared texturization that did not provide sufficient “grip” and interface strength. The result was that the geomembrane would slide over the GCL as soil was being placed up the slope, and this slippage was a construction problem. Indeed, the lead author’s experience in the field with deployment of this type of textured geomembrane above a GCL is that there is so little of the “Velcro”-effect that a slip-sheet is not needed. Typically the lead author requires a slip sheet as a mandatory accessory during deployment of coextruded-textured geomembrane above geotextile-based products to avoid snagging of the fibers (as well as concomitant dulling of the texturing). Not so in the case of this type of textured geomembrane.

Furthermore, the CQA monitor provided a photograph (Photo 2) of a location where an orange stripe had been painted across the intended tie-in of the new and old geomembranes and the underlying new GCL. The photograph clearly indicates that no movement of the unrestrained GCL had occurred in the 4-months that the disposition of the new geomembrane was being negotiated on that project. Movement of the new geomembrane was evident. In the words of the CQA monitor: “HDPE definitely moved downhill (it had pulled out of the anchor trench), but the GCL did not seem to have moved at all.”

Thus, at least for the Virginia case, tension-necking does not seem like a plausible mechanism that would have caused GCL gaps to occur on a regular basis from panel-to-panel. This case history, combined with the extensive shrinkage observed in the flat-slope case, suggests that tension-necking may not be the leading mechanism that causes GCL panel separation. Nonetheless, the GSI white paper study is still valuable for showing the propensity for necking in the presence of tension, and how much more susceptible the double-nonwoven product with no scrim fabric was to necking compared to the other products. The same type of product was also found to be much more sensitive to shrinkage from wet-dry cycling than the other products.

Current Laboratory Test Program

Following up on the comments made by Greg Richardson, the lead author organized a laboratory testing program to evaluate the effects of cyclic hydration/drying on GCLs and geotextiles. The results were able to dependably reproduce the magnitude of shrinkage found in the field. The laboratory testing program, and some of the results, are described briefly here, with a more complete and detailed description being prepared for the upcoming international conference that will be held in Yokohama, Japan next year.

The GCL and geotextile samples were cut to a dimension of 24 inches (MD) by 12 inches (XD). The samples were placed on aluminum baking pans with their as-received moisture content, and the two ends were clamped using a continuous bar-clamp screwed to the pan. The samples were in a relaxed, stress-free state when they were initially clamped. Photo No. 3 shows the initial sample setup. Two marks were precisely located near the mid-point edges of the samples, and the initial width between those marks were measured to the nearest 0.01 inch. The samples were then placed in an oven at 60° C and left to dry. This temperature was selected as representative of the temperature that black geomembrane will achieve when left exposed to the sun. After approximately 15 hours of drying, the samples were removed from the oven, allowed to cool to room temperature, and the width to the marks was measured and recorded. Approximately 500 ml of water was next evenly applied over the surface of the samples, and the samples were left to 'cure' with the water at room temperature for approximately 8 hours. At the end of the 8 hours, the width to the marks was again measured and recorded, and then the samples were placed back in the oven to dry for another cycle. Each sequence of drying and wetting was considered one cycle, and so far up to 40 cycles have been performed for selected samples. Photo No. 4 shows how one of the samples looked after 20 cycles. Note the mid-point shrinkage-necking. Since the samples were clamped at their ends, shrinkage in the longitudinal direction would also have resulted in tension in the sample, which might further exacerbate the transverse necking. The root cause of the shrinkage, necking and tension in these experiments, though, was the wet-dry cycling. One area open for more investigation would be to perform tests on specimens with different length:width aspect ratios. The length:width ratio in these tests was approximately 2. In field installations ratios of 7-10 might be more common.

The results for one GCL sample are plotted in Figure 1, which shows the percent change in width at the mid-point of the sample for each wet-dry portion of each cycle. The graph indicates that shrinkage occurs with each dry-side of the cycle, some recovery of the shrinkage upon re-wetting, but never complete recovery. For the sample shown, after 20 cycles there was approximately 10% of irrecoverable shrinkage on the wet-side of the cycle, and 20% shrinkage on the dry-side of the cycle. If the original panel width had been 15 feet, then these results would represent 1.5 to 3 feet of shrinkage, which is towards the upper end of what has actually been observed in the field. To date our laboratory testing program has been performed on 5 different fabric-encased GCL products, one geomembrane-backed GCL, one product was performed with two different amounts of water being added, and 5 different geotexiles. The range of response for the fabric-encased GCLs is about a factor of two, as shown in Figure 2. The geomembrane-backed GCL did not shrink. We have observed a slower rate of shrinkage-per-cycle when less water is added, as illustrated in Figure 3. The geotextiles by themselves exhibited very little shrinkage. Testing of additional products and matrix variables is ongoing.

Admittedly, the results depicted in Figures 1-3 represent worst-case conditions. It is unlikely that most installations would receive as much water as was added during the test, and then be dried to the extent performed in the test on a regular basis. A more likely scenario is that the magnitude of wetting and drying would be smaller on a day-to-day basis. On a seasonal basis, however, it is plausible that there may be extended periods of cool, overcast weather that would allow a fairly complete hydration of the GCL. Conversely, there may be extended periods of hot sunny weather that substantially dry the GCL. Thus, there may be small daily cycles superimposed on more significant seasonal cycles. This area definitely needs more research. A critical area that may experience the extremes simulated in the testing is at the toes of slopes, as described below.

How Much Overlap is Needed?

Although the data from this study is preliminary, the authors believe it is appropriate to publish at this time to help designers and manufacturers get a handle on the answer to the question: How much overlap is needed? Although we cannot answer this question explicitly at this time, we can point to the following variables that would influence the answer:

- The amount of shrinkage/necking is likely related to the number of days that the liner system is left exposed without soil cover. We are assuming that shrinkage only occurs when a GM/GCL installation is exposed, and that it is not an issue when the installation is covered with a minimum of 12 inches of soil.
- The amount of shrinkage/necking is likely related to the moisture conditions of the subgrade and exposure to direct sun.
- The amount of shrinkage/necking is likely related to the steepness of the slope and *Velcro*-effect of the overlying geomembrane.
- The amount of shrinkage/necking is product-specific, with double-nonwoven products containing no woven geotextile being the most susceptible to shrinkage from both wet-dry cycling and tension-necking.

At this point the authors are recommending greater than 6-inch overlaps on most projects, and considering 12 inches overlap as a standard basis for design. Allowing or requiring less or more overlap than 12 inches would be considered in light of the project-specific variables described above.

Where Do We Go From Here?

The following laboratory testing approach is being considered to develop project-specific overlap requirements for GCLs:

1. Select the GCL product to be tested. If more than one product is being considered for a specific project, run separate tests for each product. Make sure the product is truly representative of what may be used for the project, including the types of geotextiles, amount of bentonite per unit area, initial moisture content, and degree of needle-punching (as determined by a peel test).
2. Determine the maximum time duration that the GM/GCL installation will remain exposed with no soil cover for the specific project. Presume that every day represents one cycle. Admittedly this will be conservative, but at this time the authors do not see another rational choice for the selection of the number of cycles. It is reasonable that the maximum allowable exposure time is one of the specified project requirements.
3. Estimate the maximum daily temperature that the exposed geomembrane will experience. This could be a function of site location, season, geomembrane color, and whether or not the geomembrane is covered with another fabric or tarp. Data for the temperatures achieved on white- and black-surfaced geomembranes have been published by Wellington and Daniel (1995), and by Cadwallader et al. (1993). In general, it would be reasonable, and probably conservative, to assume that exposed black-surface geomembranes would achieve 60°C, and white-surface

geomembranes would achieve 40°C. These temperatures would be used during the drying stages of the laboratory test.

4. Estimate the amount of water to add for each cycle. This is the most difficult parameter to estimate. Assuming that the geomembrane installation is well-performed and sealed around the perimeter, there are only two sources for water to hydrated the GCL: (1) the initial water that was supplied within the GCL, and (2) moisture from the subgrade soils. If the GCL is polymer-coated on its bottom side, or installed encapsulated between two geomembranes, then the variable of subgrade moisture is removed, and only the amount of water that evaporates out of the GCL during the drying cycle would be available for re-wetting the GCL. If an uncoated GCL is installed against a soil subgrade, then an estimate needs to be made about how much moisture from the subgrade might be available for rehydrating the GCL. This will be very project-specific. The engineer may wish to estimate or measure the moisture content of the site soils, and depending if it is a sand, silt, or clay, use the amount of water contained in the upper 3-12 inches as a starting point for determining how much water to add back for every laboratory cycle. Note that in the field this water would be withdrawn from the subgrade due to both the temperature gradient imposed by the sun during the daytime, and by the matric-suction difference between the GCL and the subgrade soils.

Special situation: toe of slope. It should be noted that there is at least one situation that could result in significantly more hydration water available than predicted by the above method, and that is at the toe of a slope. If a water pillow forms at the toe of a slope, which is very common even for GCL installations (the authors have seen this on several CQA projects), then there will be a small zone immediately above the water pillow that will have access to a vitually unlimited supply of water (through matric suction), but will also be susceptible to desiccation during exposure to the sun. These zones might deserve special attention, such as extra overlap, or be tested more severely during the laboratory program.

With the above four variables defined for a given project, the laboratory testing program can be run using the selected GCL materials. The engineer would specify the number of cycles, maximum temperature for the drying, and the amount of water to add back for each cycle. The percent-shrinkage could then be measured on the dry-side of the cycle at the end of the testing procedure, multiplied by the width of the GCL product, and 6 inches added to represent the desired amount of overlap after all shrinkage has occurred. This would form the basis for a project-specific overlap requirement.

On steep-slope applications (e.g. 2:1 or steeper) additional overlap might be needed for tension-necking considerations.

Because of the implications of GCL shrinkage, and the observed differences in results for different GCL products and different testing conditions, the authors believe that it may be appropriate to develop a standard ASTM test method entitled something like “Dimensional Stability of GCL Materials Subjected to Cyclic Hydration and Drying”. We believe that the work performed for the current study might provide a good starting point for developing such a standard. The next ASTM meeting for committee D35 on geosynthetics is scheduled for February 9-10, 2006 in New Orleans, where we plan to bring this up. Anyone interested in attending this meeting is welcome, and could get more information regarding the ASTM meetings by visiting www.astm.org.

References

Cadwallader, M., Cranston, M., and Pegg, I. (1993) “White-Surfaced HDPE Geomembranes: Assessing Their Significance to Liner Design and Installation”, Proceedings to Geosynthetics ’93, IFAI, Roseville, MN, pp. 1065-1079.

Koerner, R.M. and Koerner, G.R. (2005) “GRI White Paper #5 - In-Situ Separation of GCL Panels Beneath Exposed Geomembranes”, Geosynthetic Institute, Folsom, PA, April 15, 2005.

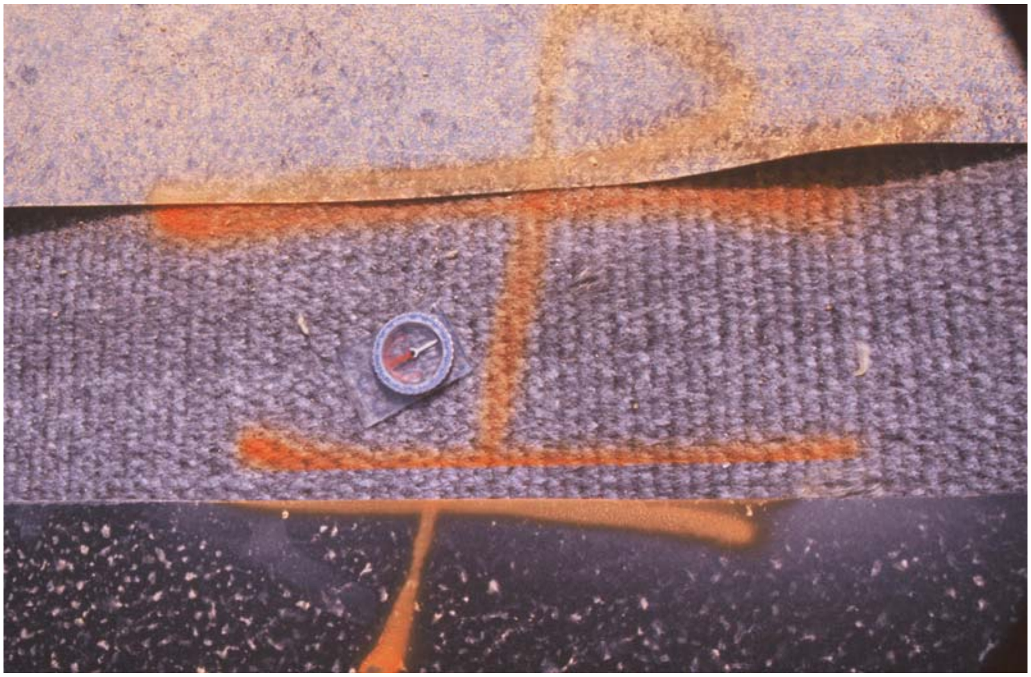
Mackey, R. (1997) “Geosynthetic clay liners, part five: Design, permitting and installation concerns”, Geotechnical Fabrics Report, January-February 1997, pp. 34-38

Thiel, R. and Richardson, G. (2005) “Concern for GCL Shrinkage When Installed on Slopes,” Proc. GRI-18 at GeoFrontiers, Paper 2.31, GII Publ., Folsom, PA, 6 pgs.

Wellington, J., and Daniel, D.E. (1995) "Desiccation of Compacted Clay Covered with White-and Black-Surfaced Geomembranes" University of Texas at Austin M.S. Thesis, Austin Texas 68 pp.

Photo 1 - Observed Field Separation of GCL Overlaps

Photo 2 – Paint Marks Showing Relative Movement of Geomembrane and GCL Over 4-Month Period. *(Note that free edge of GCL is 2 feet upwards of top of photo, beneath the pre-existing “fixed” geomembrane, illustrating zero movement of unrestrained GCL over the 4-month period. The new geomembrane, toward bottom of photo, has clearly moved.)*



Photos 3 and 4: Shrinkage Study Sample Before and During Test Cycles

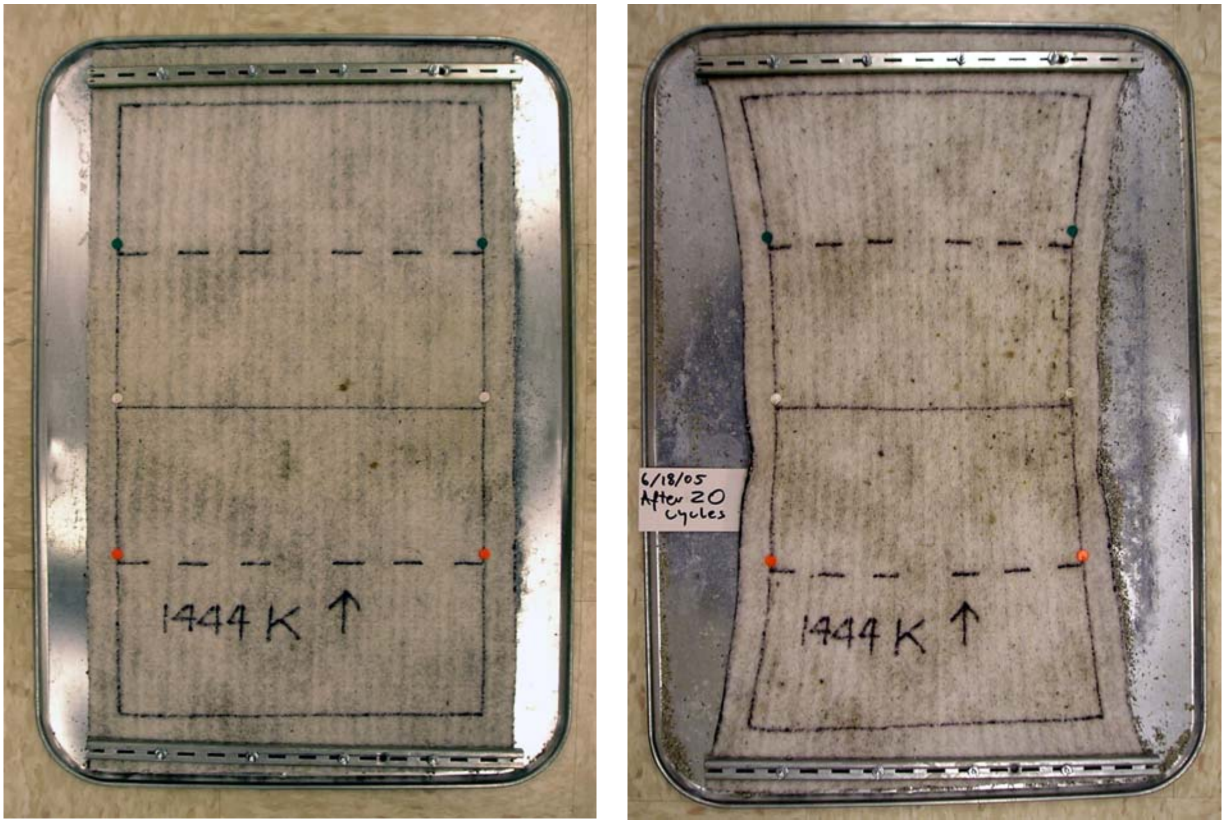


Figure 1: Shrinkage of Sample Direction During Test Cycles: in Cross-Machine

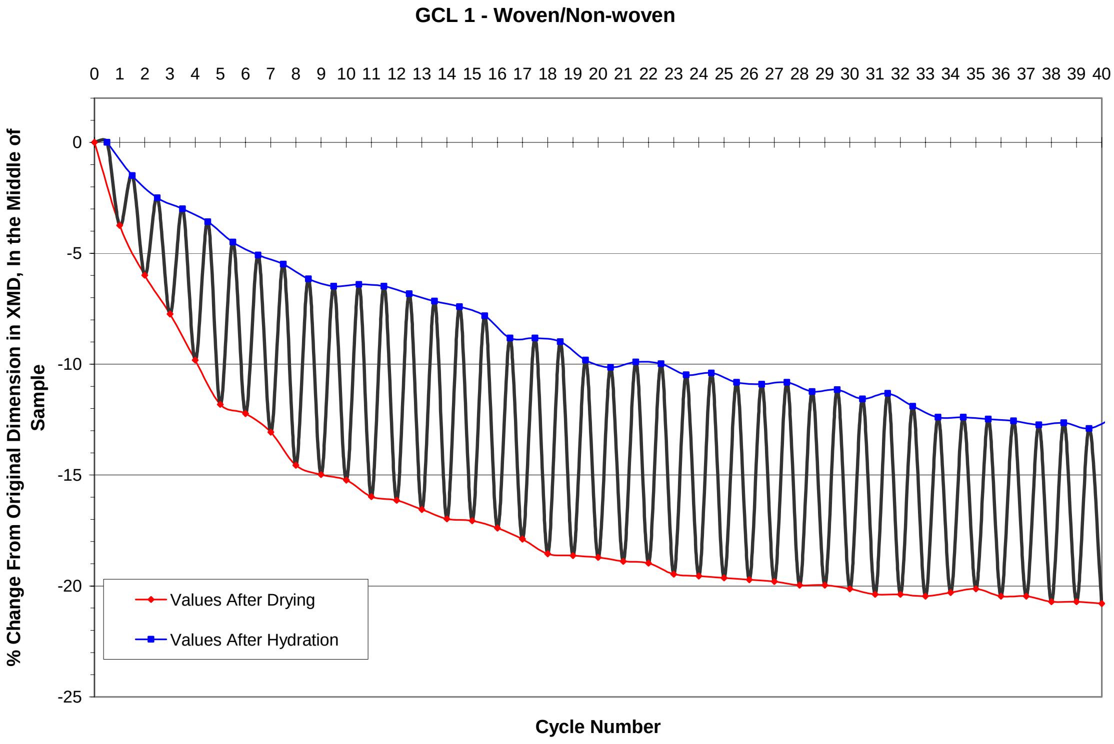


Figure 2: Comparison of Dry-Cycle Shrinkage Results of 5 Different Products

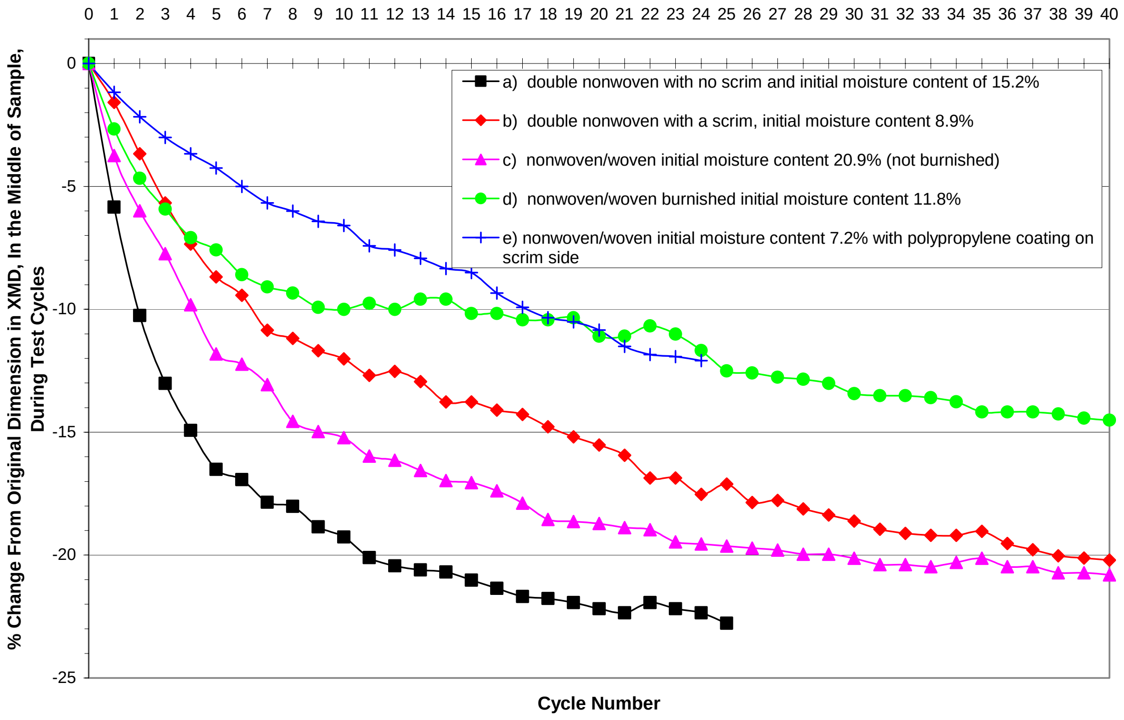
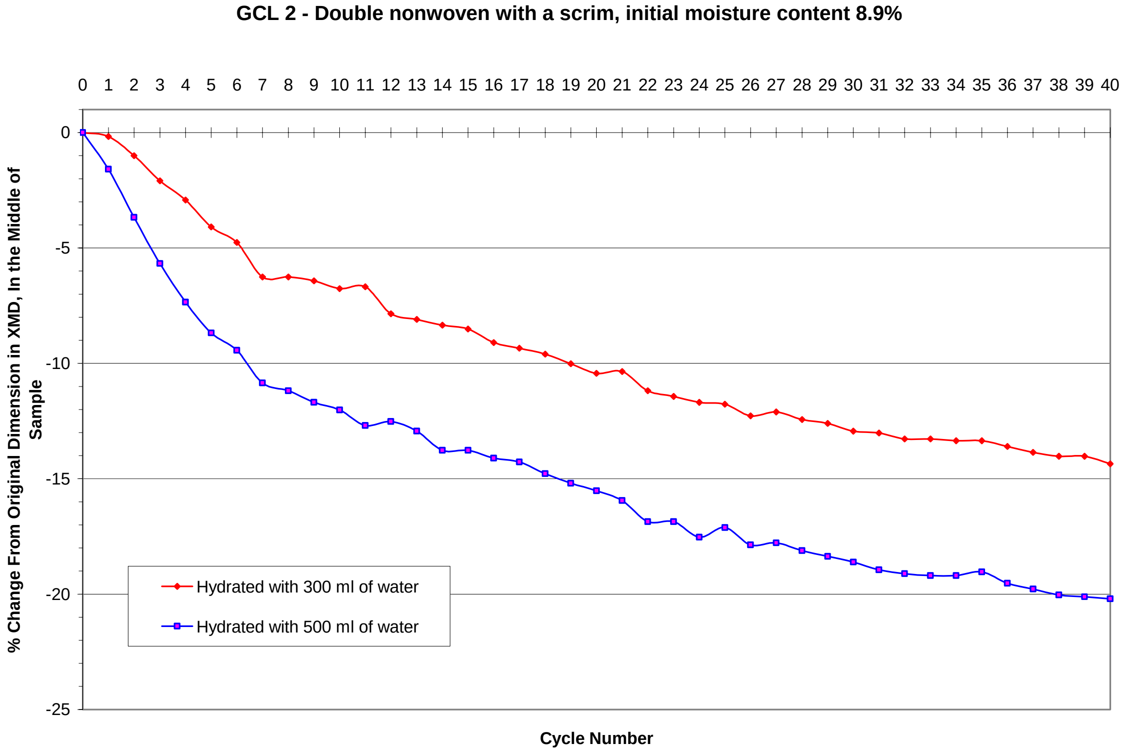


Figure 3: Comparison of Shrinkage Results with Two Different Amounts of Water Addition on One Product



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