An Assessment of Vinyl Sheet Piles for Long Term Applications

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An Assessment of Vinyl Sheet Piles for Long Term Applications

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ABSTRACT

There are concerns about the integrity of vinyl sheet piles over its long-term use. Cold weather and ultraviolet rays are known to cause the performance degradation (increased brittleness) of vinyl plastics. This paper summarizes preliminary results on the impact performance under low and high velocity impact of polyvinyl chloride (PVC) samples exposed to 20 and 200 hours and compared to unexposed control samples. The results show that the low velocity impact response was minimally influenced by the UV exposure. At high velocities no indications of damage were seen, the projectile simply bounced off. The UV exposure increased the ballistic limit due to surface hardening.

KEY WORDS: PVC; UV degradation; Impact; Durability; Long-term application; Sheet piles; PVC sheet piles; Retaining Walls

INTRODUCTION

There are concerns (refer US Army Construction Bulletin 28 Oct 2002) about the integrity of vinyl sheet piles over its long-term use. Cold weather and ultraviolet rays are known to cause the performance degradation (increased brittleness) of vinyl plastics. The raw material for vinyl sheet pile fabrication is usually recycled vinyl mixed with some percentage of virgin material and UV inhibitors. Questions have been raised whether the sheet piles made with such reprocessed vinyl will be durable over 50 years or not. Also, exposed vinyl sheet piles can be easily damaged accidentally or by vandalism. Apparently there exists no report from any systematic study on the long-term durability of vinyl sheet piles, nor there is any design guidance document like EM 1110-2-2504 on its selection and application. In the Corps of Engineers ETL1110-2-548 dated 31 March 1997 Dutta has noted that the physical aging of thermoplastic polymers (to which the vinyl group belongs) may continue for very long time; as a result, they may become stiffer and brittle. This paper summarizes preliminary results on the impact performance under low and high velocity impact of polyvinyl chloride

(PVC) samples exposed to 20 and 200 hours and compared to unexposed control samples.

A polymer such as PVC can undergo degradation in two stages during its lifetime. One, during its fabrication and the second during its usage. The degradation at molecular level is mainly brought about by radiant, thermal and chemical exposure. The radiant energy sources may be gamma rays or ultra-violet (UV) rays. There are artificial and natural sources of the UV radiation. Some polymers have been reported to undergo chain-scission on exposure to radiation while cross-linking is observed in others. The exact effect depends on the structure of the polymer and nature of radiation. The artificial sources include sunlamps, mercury vapor lamps etc. The sun is a natural source of UV radiation. UV radiation consists of three main components namely UV-A, UV-B and UV-C. The UV-A radiation (320-400nm) is slightly affected by ozone levels, so the earth's surface is composed of a large amount of this radiation. The physical units of the dose intensity being Joules per square meter, Watts per square meter or microwatts per square centimeter. UV-B radiation (280-320nm) is strongly absorbed by ozone levels in the stratosphere and only small amount reaches the earth's surface, but with the thinning of the stratospheric ozone more UV-B can reach the earth's surface, thus becoming an environmental
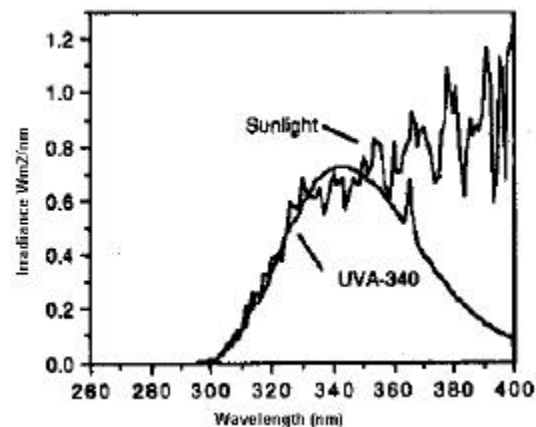

Figure 1. Representative Spectral Power Distribution of UVA-340 Fluorescent Lamps [ASTM]

problem. The UV-C radiation (100-280nm) is destructive and causes most damage to the biosphere, but it is completely absorbed by ozone and oxygen molecules in the upper atmosphere, so this is of little importance.

Ramani et al. (2000) studied the response of oxygen containing (polycarbonate) and oxygen free (acrylonitrile-butadiene-styrene) polymer where they investigated the degradation of these polymers upon exposure to UV radiation. They reported that in both polymers in the early stages of irradiation chain-scission leading to free radical formation is the predominant process. Radiation induced cross-linking becomes dominant in the later stages of irradiation. An interesting feature reported in the studies was that an oxygen-containing polymer attains photo stability at longer UV exposures which is attributed as due to the formation of photostabilisers whereas no such stability is observed in the case of an oxygen free polymer. However Tomasella et al. (1995) have suggested that UV light which delivers polyvinychloride (PVC) energy of about 10 eV, very close to its chemical bond energy could be more selective and well absorbed by PVC. Also upon irradiation, PVC can undergo either cross-linking or degradation. PVC has been reported to undergo cross-linking under such conditions [Chapiro (1962), Charlesby (1960)]. However another work reported by Rao et al. (1995) with UV exposure there is degradation of PVC in terms of dehydrochlorination. Also according to the report this rate of dehydrochlorination and polyene distribution increases with the increase in UV radiation time.

Susceptibility to impact is often of concern for outdoor applications. This paper focuses on the impact behavior of exposed and unexposed PVC samples at low to intermediate velocity impacts such as would occur in field applications for sheet piles.

EXPERIMENTAL

In this study we have investigated the UV-A 340 nm type radiation (Fig. 1). A South New England Company Photochemical Reaction Vessel RPR-200 equipped with 16 lamps of 350 nm primary wavelength circumferentially arranged was used to expose the samples to UV radiation. The intensity of the 16 lamps output from the UV equipment is approximately 9200-9500 microwatts per square centimeter at the center of the specimen chamber, which is about 5 times the intensity encountered on a clear sunny day in a place like Arizona. The intensity of the UV radiation in outdoor conditions would by approximately 1500 – 2000 microwatts per square centimeter. It must be noted that these are only approximate guidelines, the cloud conditions, air quality, pollution etc. influence the actual values of radiation to a large extent.

Three sample types cut from a commercially available UV stabilized PVC sheet pile were considered: a) control (unexposed) samples, b) 20 hours UV exposed, and c) 200 hours UV exposed respectively. The UV test chamber had 9" x 12" accessible space for holding the samples. The UV testing involved exposure of 10 samples of nominal size of 4" x 4" x 0.5". Two samples each were connected using eyehooks and hung from the top of the UV chamber using a nickel wire. Five sets of these samples were hung together in the chamber. These samples were further rotated to various positions to get same amount of exposure for each individual sample. The samples exhibited notable discoloration upon exposure, both for the 20 h and the 200 h respectively. The 200 h-exposed samples were almost brownish in color, while the 20 h were light yellow. Figure 2 illustrates the discoloration due to degradation for the 20 h and 200 h samples in comparison to the control sample.
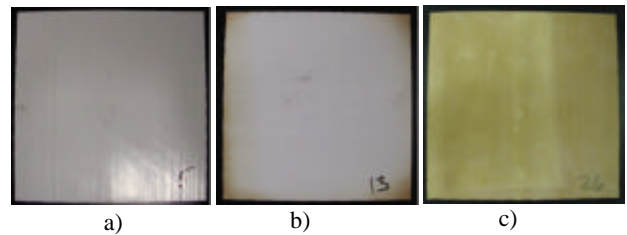

a)   b)   c)

Figure 2. a) Control sample, b) 20 h exposed sample, and c) 200 h exposed sample

Low Velocity Impact

Low velocity impact (LVI) tests were conducted to evaluate damage initiation of the PVC. A few representative samples of polycarbonate (PC, also referred to as Lexan®) were included in the study for the purposes of comparison. For comparison of PVC behavior to PC, a PC sheet of equivalent thickness as the PVC was used. The PVC and PC samples (ASTM 3763-93). PC was not subjected to UV tests, but only for comparison with the control. The equipment used to conduct the tests is an instrumented Instron 8250-drop tower. The basic principle of operation is to drop a impactor of known weight from a set height onto the test sample. The maximum load and maximum energy absorbed by the test sample and the damage to the sample is assessed.

For the PVC control, PVC 20 h UV exposed, PVC 200 h UV exposed, and PC samples, the drop height, and mass where held constant at 39.37 in (100 cm) and 51.59 lb (23.4 kg) respectively. A 9892 lbf (44 kN) load cell along with a 0.625 in (15.875 mm) diameter hemispherical tup (impactor) was used. The specimen fixture is composed of two aluminum plates, with 3 in diameter holes, bolted together with the specimen residing in between.

The load, energy, time curves for the PVC control, PVC 20 h UV exposed, PVC 200 h UV exposed, and PC samples is shown in Figure 3. All samples exhibited similar energy absorption, the 200 h exposed samples exhibit a slightly higher peak load, followed by the 20 h and the control. The front and back face deformation for each specimen tested is shown in Figure 4a-f. For all PVC samples (exposed and control), the samples exhibited indentation equivalent to the tup diameter, and slight bulging on the back face. The indentation was highly localized, and no radial cracking or tensile side fracture was observed under LVI for any of the PVC samples. The PC underwent the highest depth of penetration, and exhibited some radial cracks initiating from the indentation location on the tensile side.

The depth of indentation was quantified. Table 1 shows absolute values of the indentation depth on the y-scale. The percentage indentation is calculated as the ratio of the penetration depth to the nominal specimen thickness. The PC specimen exhibited the highest depth of penetration (38.7%) followed by the PVC control (28.3%), PVC 20 h (27.6%), and the PVC 200 h (23.5%) specimens. The 200 hour exposed samples had a brownish 'skin' limited to a few microns from the surface. This leads to increase in surface hardness, and reduces the indentation depth as compared to the control. This is also consistent with the trends observed in peak loads (Fig. 3), i.e., the higher surface hardness of the PVC 200 h resulted in its higher peak load than the 20 h and the control sample.
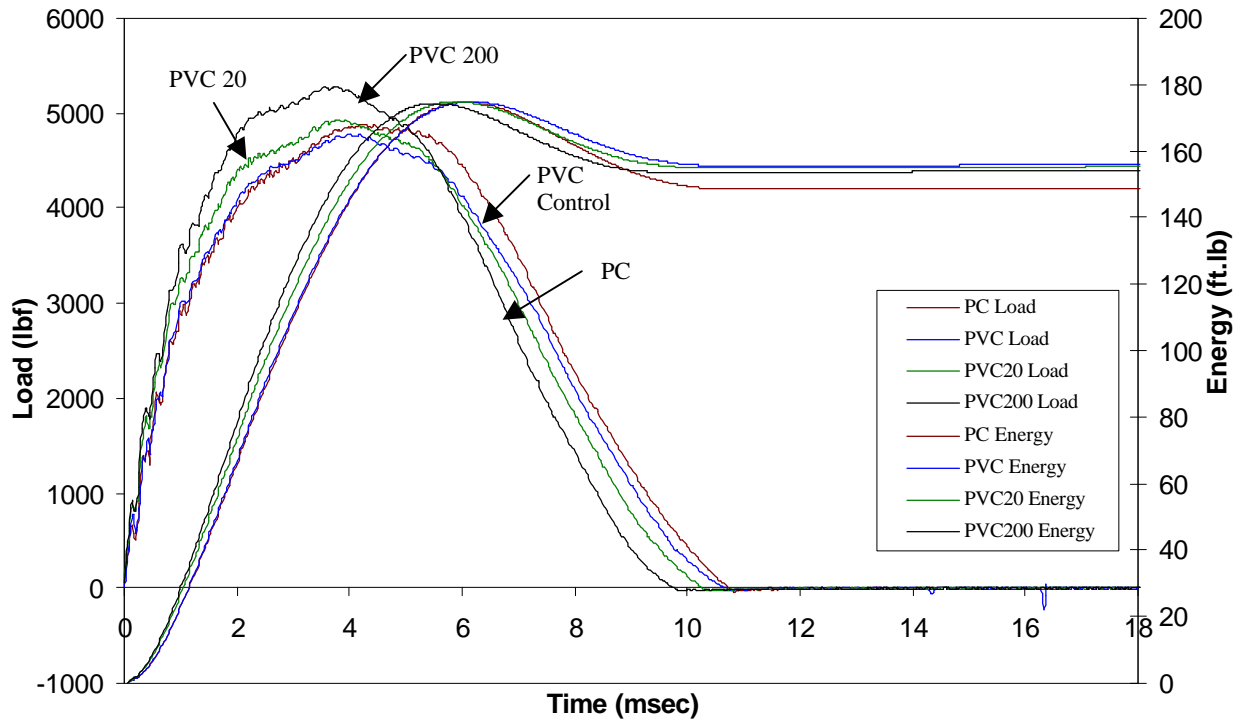
Figure 2. Force-Energy-Time curves for PVC control, PVC 20 h, PVC 200 h, and PC samples
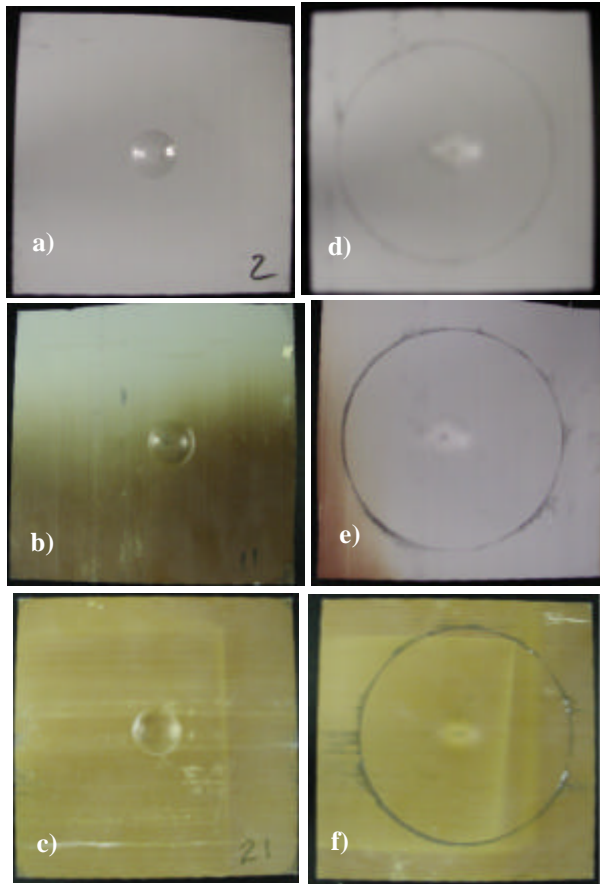

Figure 3. Low velocity impact of PVC samples. a-c represent impact face, d-e represent back face, a, d) control, b,e) 20 h exposed, c,f) 200 h exposed
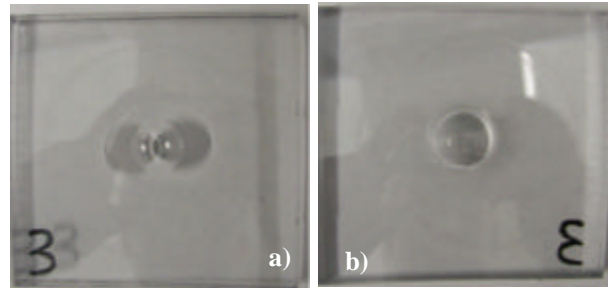

Figure 4. Low velocity impact of unexposed PC, a) impact face, b) back face

Table 1. Indentation Measurements from LVI specimens

Specimen	Indentation (inch) mm
PVC Control	(0.139") 3.54
PVC 20h	(0.135") 3.45
PVC 200h	(0.115") 2.94
PC	(0.190") 4.84

High Velocity Impact Tests

Tests were extended to include high velocity tests in a gas gun. These impact tests represent debris type hits to sheet piles. A gas gun apparatus consisting of a pressure tank, remote firing valve, barrel, and capture chamber was used. Nitrogen was used as the working fluid and was regulated to control the velocity. The velocity of the projectile was measured through transparent windows with light chronographs attached to the capture chamber. The sample was rigidly clamped on two sides inside the capture chamber. A hemispherical projectile made of tool steel with a mass of 14.2 g (0.03124 lb) was used. A polyurethane foam sabot carries the projectile through the barrel and the sabot is stripped off by a stripper plate prior to impacting the specimen. The impact results of the PVC control, PVC 20 h, PVC 200 h, and PC specimens are shown in Figure 5. Figure 6a-d shows the deformation produced in each of the specimens by the projectile.
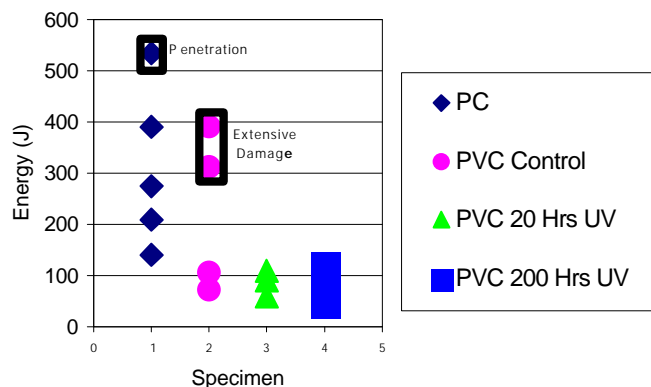

Figure 5. High velocity impact tests

The PC samples shows very localized damage and absorbed almost 500 J prior to penetration. Up to 120 m/s all PVC samples showed little or no indication of damage. The projectile simply bounced off, leaving a small indentation up to the penetration limit. At a threshold velocity of around 120 m/s, corresponding to approximately 120 J energy, multiple radial cracks were observed as shown in Fig. 6. The exposed and control PVC samples show identical damage. The 200 h UV exposed sample exhibited higher threshold damage limit (from 122 m/s to 130 m/s), which can be attributed to the surface hardening of the 200 hour UV exposed samples. Similar trends were observed in LVI.

CONCLUSIONS

- The UV exposure added a 'skin' like feature to a few microns of the surface of the PVC samples.
- There was severe discoloration of the samples after the 20 hour and 200 hour UV exposures
- The low velocity impact response was minimally influenced by the UV exposure. No radial cracking on tensile side was observed, all PVC samples showed local indentation, and small bulge on the back face. The tests showed a peak load of about 25-30kN and energy absorbed of about 30 J.
- The higher velocity tests indicated that the PVC had a threshold damage limit of 122-130 m/s, to cause radial cracks growing from the impact location. Up to 120 m/s, no indications of damage were seen, the projectile simply bounced off. The UV exposure increased the ballistic limit due to surface hardening.
- Polycarbonate of equivalent thickness exhibited similar low velocity impact characteristics as the PVC. Under high velocity impact, the polycarbonate outperformed the PVC and exhibited a damage limit of approximately 250 m/s (about 450 J), as opposed to the 122 m/s for the PVC. However, polycarbonate is much expensive than PVC.
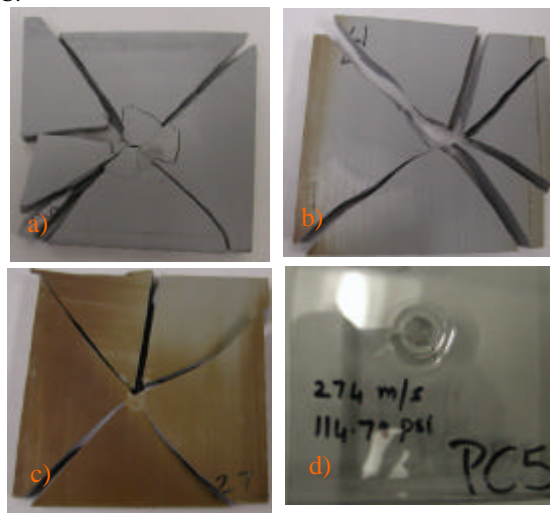

Figure 6. High velocity impact failure of a) Control PVC, b) 20 h exposed PVC, c) 200 h exposed PVC and d) unexposed PC

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