Rapid Prototyping of High Strength Geosynthetic Interfaces: Interim report February 2016

Fu, L., Fowmes, G.J.
School of Civil and Building Engineering, Loughborough University, LE11 3TU, UK.

This project investigates the use of rapid 3D prototyping techniques to produce geomembranes with high interface shear strength to facilitate higher and steeper slope for containment facilities. This involves the feasibility study of applying different production approaches in attempting to improve the shearing strength of geomembranes, including the Laser Thermal Ablation (LTA) for a subtractive process, and Selective Laser Sintering (SLS) for an additive manufacturing alternative. The LTA method removes excess material from an over thick polymer sheet, whilst SLS "prints" a new material.

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The pattern design

The stability design method for geomembrane on a slope can be shown in **Fig.1**. On a side slope, geomembrane is undergoing a vertical downforce from the weight of waste (Wa), and a normal support force (Fa) from the side slope of the soil. Thus the total force combined in normal direction is the difference between Fa and normal components of Wa and the mass of membrane on slope (Wm), as seen in **Equation - 1**. The total force combined in shearing plane direction is the difference between friction (F*f*) and shearing components of Wa and Wm (**equation - 2**).

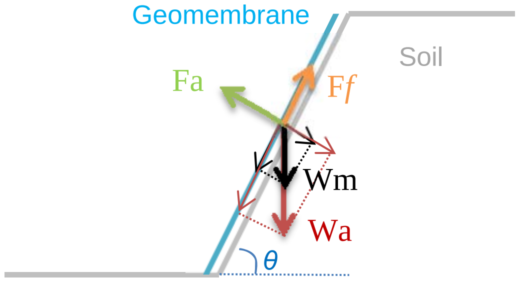


Fig.1. The stability design method for geomembrane on a slope.

Normal direction:

$$F_{normal} = Fa - Wm\cos\theta - Wa\cos\theta \qquad \textbf{(equation - 1)}$$

Shearing plane:

$$F_{shearing} = Ff - Wm\sin\theta - Wa\sin\theta \qquad \textbf{(equation - 2)}$$

As seen in **equation-2**, the stability of geomembrane on a steep slope can be improved by maximizing the total force combined in shearing plane direction – $F_{shearing}$. This can be achieved by: 1) an increased frictional coefficient of the geomembrane material; 2) an additional upward force along the shearing plane. As the slope becomes steeper, the friction

F*f* reduces radically due to a reduction in pressure to soil. This motivates a series of new designed textured patterns on the surface to introduce an additional resistance along the shearing plane.

In a LTA process, unwanted material is eliminated through the photothermal ablation effect. The above different patterns were “carved” into the top of smooth HDPE geomembrane samples by a 10.6μm CO_2 laser with the X-Y plotting stage (**Fig.2**). As seen in **Fig. 3 and 4**, the ablated area was thermally removed by a moving laser beam, leaving a 3D surface pattern with its height of the structure at around 1mm.

(a) (b)

Fig.2. A schematic illustration of the LTA process (a), and a 10.6μm CO_2 laser with the X-Y plotting stage used in this project (b).

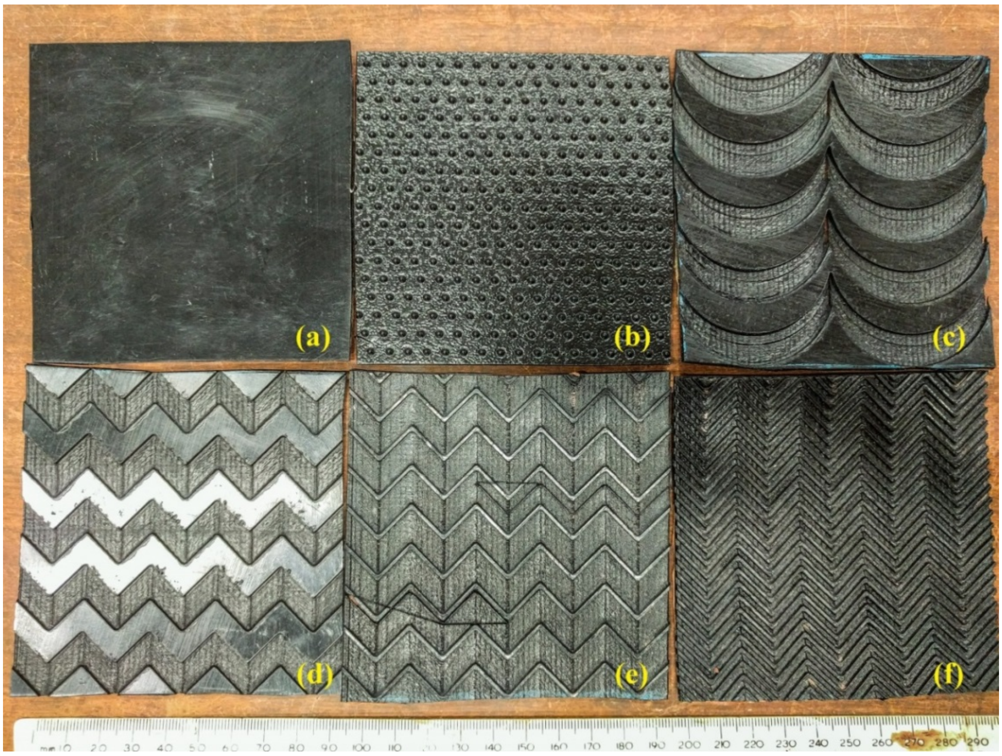


Fig.3. HDPE geomembranes – (a) factory smooth (b) factory spiked (c) LTA arc (d) LTA zig-zag A (e) LTA zig-zag B (f) LTA zig-zag C.

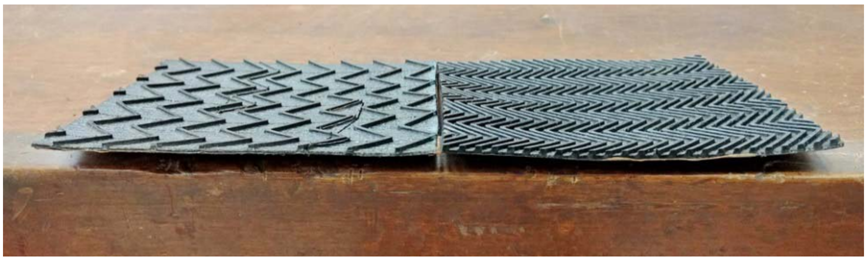


Fig.4. A side-view of LTA samples with a zig-zag pattern.

Shear assessment for both of the factory made geomembrane (smooth and spike-like shape) and ablated geomembrane samples were conducted using a direct shear apparatus. The shearing result for geomembrane against clay (with 17% moisture content) in undrained condition with 50 kPa normal stress can be seen in **Fig.5**, and **Fig.6** shows the shearing result with 400 kPa normal stress.

As seen in **Fig.5**, in presence of a low normal stress at 50 kPa, the shearing strength of geomembrane with both of the arc-like pattern (**Fig.3-c**) and zig-zag-like pattern (**Fig.3-d**) is higher than that of factory smooth and spiked like geomembrane. In shear box test with 400 kPa normal stress loading, geomembrane with three different zig-zag like patterns were tested (**Fig.3-d,e,f**). As can be seen in **Fig.6**, zig-zag like pattern with narrower width and wider gap (zig-zag B) made more contribution in improving the shear strength of the material than any other patterns, which is indicative of such zig-zag like pattern can effectively provide an additional resistance at the shearing plane.

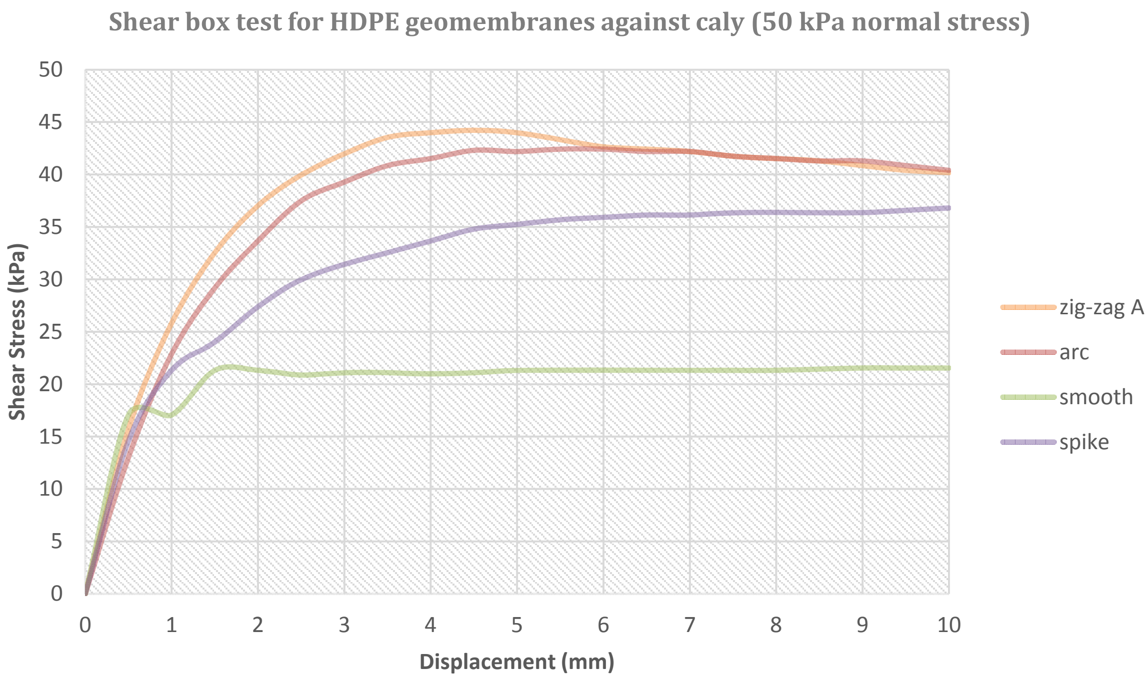


Fig.5. Shear stress Vs. displacement for HDPE geomembranes against clay at 50 kPa normal stress.

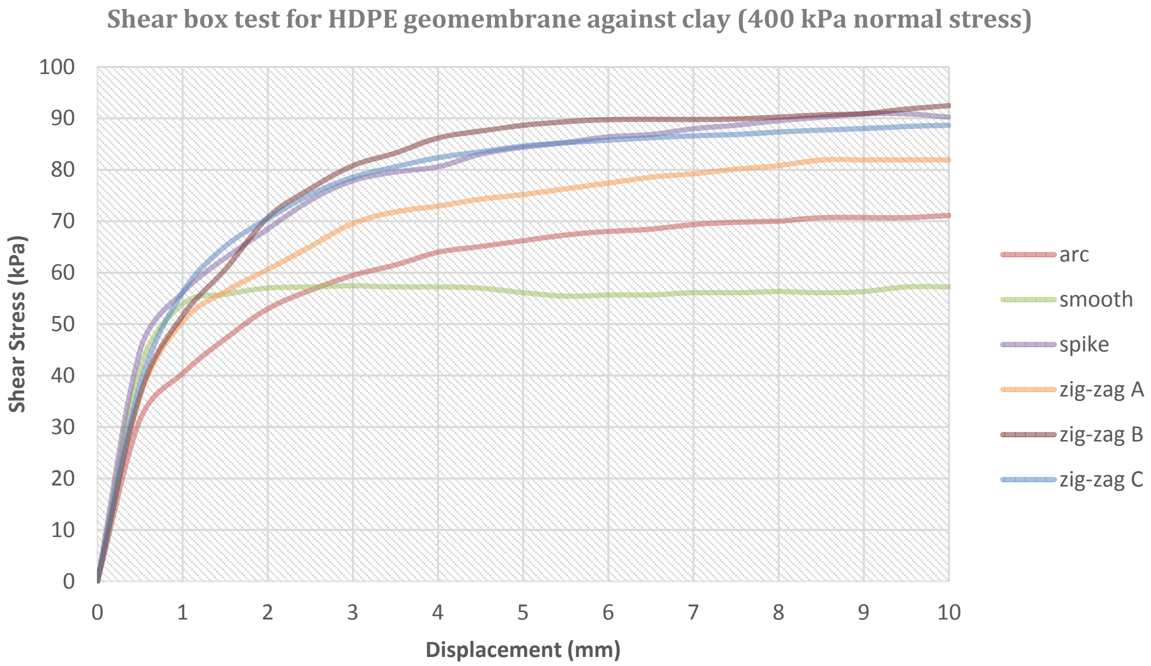
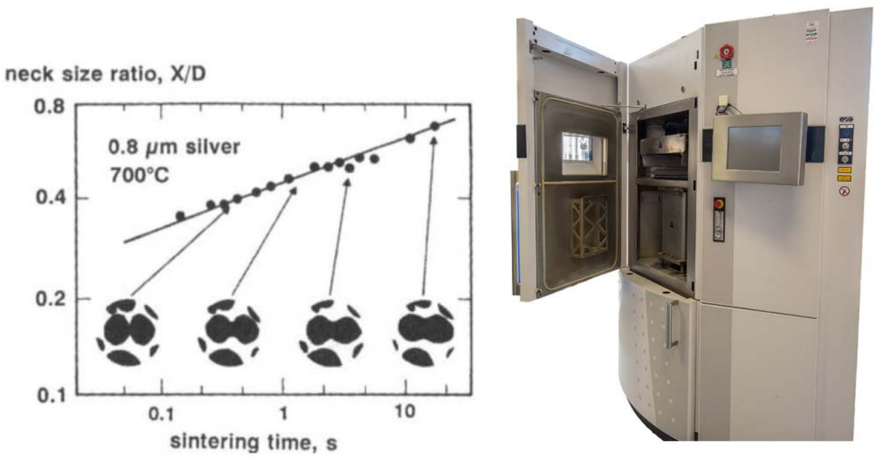


Fig.6. Shear stress Vs. displacement for HDPE geomembranes against clay at 400 kPa normal stress.

Selective Laser Sintering (SLS)

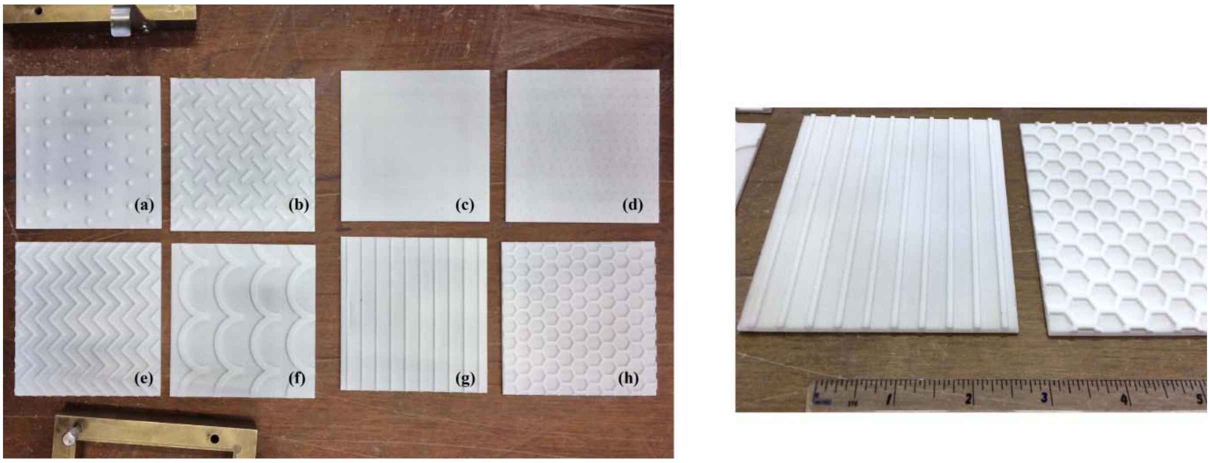
Unlike the LTA process which eliminates unwanted material from its own structure, the SLS process produces the designed structure from a powder bed which is containing micro- or nano-particles. As seen in **Fig.7**, In a SLS process, a rigid structure is formed from powders through the sintering effect, in which small particles are melted when exposed to a high energy beam such as laser beam, and are bonded together through a so called “neck-formation” stage. Also unlike the LTA process – which its complex 3D capability is restricted due to a “shadowing limitation”, the SLS process can produce a more complex 3D structure such as a hook shape layer upon layer.



(a) **(b)**

Fig.7. A typical illustration of the necking formation during the sintering process for 0.8μm Ag particles at 700°C [1] (a), and the EOS Formiga P100 Additive Manufacturing System used for a SLS process in this project (b).

In this SLS research, polyamide (PA) microparticles (particle size~60 micron) were chosen as the raw material to produce replicas of HDPE geomembrane. Replica samples after SLS process can be seen in **Fig.8**.



(1) (2)

Fig.8. SLS replicas (1) – (a) large asperities (b) high friction (c) smooth (d) small asperities (e) zig-zag (f) semi circle (g) flat ridge (h) bee-hive. A close view of flat ridge and bee-hive samples is presented in (2).

The same shearing test with 17% moisture content clay in undrained condition was also conducted to investigate the change in shearing stress for SLS samples. As seen in **Fig.9**, the peak stress at around 62 kPa was achieved by sample with a zig-zag like pattern, which is another indicative of supporting the zig-zag like pattern can effectively improve the shearing strength of the material, particularly on a steep slope.

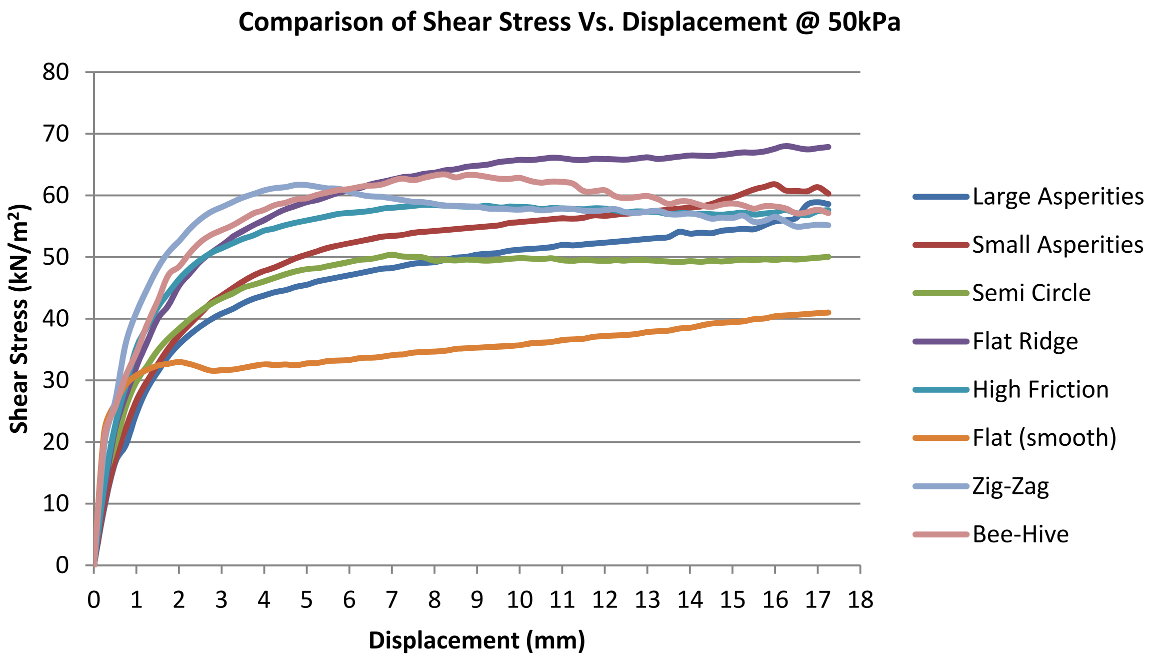


Fig.9. Shear stress Vs. displacement for SLS replicas against clay at 50 kPa normal stress.

Conclusions and recommendations

In this project, two different manufacturing processes – the Laser Thermal Ablation (LTA) process and the Selective Laser Sintering (SLS) process were chosen and used in this investigation. 3D textured patterns were produced by removing unwanted structure of HDPE geomembrane (LTA) and sintering Polyamide micro-particles layer-upon-layer (SLS). Both of the LTA and SLS manufactured samples were tested against clay with 17% moisture content in a direct shear apparatus. The shearing result indicated the sample with a zig-zag like textured pattern on its surface can effectively improve the shear strength of the material.

In the future, a more complex 3D textured pattern will be investigated to further improve the shear strength of the geomembrane on a steep slope. This includes a comparative study of geomembrane with different complex 3D textured patterns against clay/sand/geosynthetic product in a direct shear apparatus, and the SLS process using HDPE micro-particles.

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Reference

[1] Pique, A. and Chrisey, D.B. (2002) Direct-Write Technologies for Rapid Prototyping Applications: Sensors, Electronics, and Integrated Power Sources, SanDiego: Academic Press.