Short Communication

Screw pullout behaviour in polyethylene

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Abstract

Plastics are now rapidly displacing conventional materials in numerous engineering applications in mass productions. The emerging need to produce larger and more complex forms of plastics and their composites has increased the need for joining, in particular, the thermoplastics. Thread fasteners have found widespread use in many systems and structures. Although frequently overlooked they represent a complex and often critical design element. Fastened assemblies are often subjected to dynamic environments including vibration, shock, and/or thermal cycling. Such conditions can lead to fastener loosening and can result in increased maintenance and failure.

In this study, the effect of thermal cycling and different environmental conditions upon the pullout performance of screwed polyethylene in semi-crystalline thermoplastic was examined.

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1. Introduction

The plastic industry has grown rapidly since its inception in the 1940s. In the past, and to a certain extent today, plastic engineering components have been designed to directly replace components in traditional engineering materials, leading to poor performance and costly reproduction. For effective material substitution, the designer using plastic has to appreciate benefits as well as limitations. Today its designs are being produced that are not only unique to plastics but also out-perform designs in traditional materials. For example, in automotive industry, many components made from plastic or composite materials can range from body panels, radiators and ignition components to structural and semi-structural components such as bumper beams, front-end panels and leaf springs. The prospect of lighter, more durable components together with the increased design freedom, relatively low investment costs and parts consolidation opportunities that advanced composite technology offers is expected to see its popularity grow [1–5].

Polymers are classified as either natural or synthetic. There are two generic classes of synthetic polymers: thermoplastics and thermosets. Thermoplastics can be softened and melted by heating and hardened on cooling repeatedly without degradation. Therefore, thermoplastic parts can easily be joined or formed by various manufacturing processes. There are many techniques used for joining of plastic materials, but based on the method used, they are classified generally into three groups: welding, adhesive joining and mechanical fastening [1–4].

Industrial products are very rarely monolithic. The problem of joining components is therefore a key issue in the design process. Joining components is a way of allowing simpler forms for the individual components, which are thus easier and cheaper to process. However, very often joints are weak points from a mechanical or chemical viewpoint: for instance many failures in fatigue or in corrosion occur at welded joints. In order to avoid these problems, special processing conditions or non-destructive testing have to be used, depending on the joining method and these inevitably lead to extra cost in making the product. Joining is also a problem from the efficiency viewpoint: it often needs some extra material to be added to the structure (such as screws, bolts, or welding filler metals). It sometimes leads to local weakening of the mechanical

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properties of the material of the components (for instance, in the heat affected zone of weld). All these aspects usually lead to the application of safety factors and thus an increase in mass needed to fulfil a given structural function. In general, the number of joining operations has to be minimised in order to decrease the overall cost of a product. Moreover, recent trends toward recycling may lead the designer to consider disassembling as well as assembling components. Selecting the appropriate joining method, as well as designing the components while keeping in mind the joining problems, is an important aspects of efficient design.

Manufacturing and assembling of composite and plastics structures require knowledge of reliable joining techniques. Threaded fasteners are generally used in assemblies when a load-bearing connection that can be disassembled without destructive methods is required in a design. Mechanical fastening is a common method used to join composite and plastic materials. Thread fasteners have found widespread use in many systems and structures including transportation systems, orthopaedic fixations, structures, automobile, aerospace vehicles, and electronic equipment. Mechanically fastened joints commonly adopted in aerospace structures are characterised by tight tolerances on both the fasteners and the machined holes. As a consequence, knowledge of the effect of tolerances between the fastener and the hole on the strength and fatigue life of mechanically fastened joints will be required for the design and selection of manufacturing process [6–11].

A mechanically fastened joint can be manufactured in a short time. In fast assembly, a mechanically fastened joint can be performed with robots. The components have a long life and they are set easily. The operation cost is low. Dissimilar materials can be joined with thread fasteners, but a mechanically fastened joint has some disadvantages. Thermosetting adhesive bonding is inherently preferable to mechanical fastening because the continuous connection avoids large stress concentrations induced at each discrete fastener hole. Adhesive bonding joint has high fatigue resistance. Adhesive bonding structure absorbs high energy and distributes stress. Stress concentration decreases on smooth surfaces. Different materials can be joined with adhesive bonding. However, there are a wide range of contaminants present on substrate surfaces, including silicon release agents and bagging materials, fluorocarbon release sprays and films, machining oils, fingerprints and components of composite itself which have migrated to the surface (calcium stearate, water and plasticizers, etc.). These need to be eliminated prior to bonding by using a surface preparation treatment which may also serve to improve wetting of low energy surfaces, (introduction of polar groups or coupling agents) and increase the surface roughness (improving mechanical interlocking and increasing bonding surface area). Extensive surface preparation and long curing times make adhesive bonding labour intensive. Sensitivity to storage is another restrictive aspect of surface treatments [1,12]. Comparison between various joining techniques of plastic is given in Table 1 [12].

Thermoplastic polymers can be mechanically fastened using both threaded and unthreaded fasteners and, to a far lesser extent, by integral, interlocking design features. Because thermoplastics are often lower in strength than thermosets, they are more prone to visco elastic deformation or cold flow. Thus, fastener design must be carefully considered, for both the fastener holes (e.g. hole placement relative to edges).

As for thermosets, fastener loading should be distributed as much as possible to avoid stress concentration that will cause deformation. Heads and feet of fastener systems should be as large as practical, or washers should be employed, and holes ought to be sleeved. While uncommon, especially for true structural applications, fasteners that are themselves made from thermoplastics might be ideal for mechanically fastening thermoplastics [5].

For most removable fasteners to function optimally, several factors need to be taken into account. These include

- Material selection
- Clamp load

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Comparison between various joining techniques on a scale from 0 (least suitable) to 10 (most suitable) [12]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mechanically fastening</td>
</tr>
<tr>
<td>Performance</td>
<td>4</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>10</td>
</tr>
<tr>
<td>Durability</td>
<td>5</td>
</tr>
<tr>
<td>Cost*</td>
<td>2–7a</td>
</tr>
<tr>
<td>Processing time</td>
<td>2</td>
</tr>
<tr>
<td>Minimal surface preparation</td>
<td>2</td>
</tr>
<tr>
<td>Flexibility</td>
<td>10</td>
</tr>
<tr>
<td>Large scale joining</td>
<td>10</td>
</tr>
<tr>
<td>Portability/application to repair</td>
<td>10</td>
</tr>
<tr>
<td>Automation/production Environment</td>
<td>10</td>
</tr>
<tr>
<td>On-line inspection</td>
<td>5</td>
</tr>
<tr>
<td>Reprocessing/recycling</td>
<td>10</td>
</tr>
</tbody>
</table>

* First cost rating corresponds to small volume productions, e.g. parts >10, second rating corresponds to large volume production.
• Torque
• Pull-out force
• Dynamic stability
• Repeat assembly
• Corrosion resistance

It is important that these factors be considered early in the design of an application, rather than as an afterthought, to ensure optimal joint performance. Besides these elements, sheet metal and thin wall components present additional challenges to joint design. First is thread engagement.

Mechanically fastened joints, including riveted and bolted joints, are used to connect composite structures where component disassembly is scheduled regularly. Because of the introduction of a bolt-loaded hole, high-stress concentrations reduce the structural strength significantly at joint connections [11,13–15].

The threaded fasteners have found widespread use in many systems and structures including transportation systems, orthopaedic fixations, structures, and electronic equipment. Although frequently overlooked they represent a complex and often critical design element. Fastened assemblies are often subjected to dynamic environments including vibration, shock, and/or thermal cycling. Such conditions can lead to fastener loosening and can result in increased maintenance and failure [11–17]. The common causes of the relative motion in bolted joints threads are

1. Component bending that results in forces being induced at the friction surface. If slip occurs, the head and threads will slip, which can lead to loosening.
2. Differential thermal effects caused by either differences in temperature or differences clamped materials.
3. Applied forces on the bolted joint can lead to shifting of the joint surfaces and eventually to bolt loosening [11].

Thermoplastic composites are more and more used in applications in which they are exposed to severe environments combining temperature and moisture. In the literature, many studies are dedicated to the hygrothermal ageing of various polymer matrices and their composites: high temperature engineering polymers, polyamides, and polyesters. Fouc found that the mechanical strength of composite decreased with hygro thermal ageing [18].

A particularly sensitive and simple method for assessing elastomer degradation is the swelling test (i.e. water absorption). Since attack by certain chemicals (e.g. chloramines) leads to the rupture of crosslinks, micro cracks form on the surface of materials that allow contact solutions to penetrate the elastomer. The attack then becomes auto-accelerating, since as the cracks deepen they expose new materials to chloramines. The tendency of elastomers to absorb chemical solutions correlates closely with the loss of their physical properties (i.e. maximum strain and stress).

The water absorption test is fast (the accelerated testing can produce measurable water absorption in only a few days) and requires a minimum of laboratory equipment. It is also highly sensitive and reproducible. The water uptake test is a modification of the ASTM rubber swelling test (ASTM D412-83). This involves carefully weighing the samples prior to exposure. After exposure, surface water is removed by towelling and then the samples are immediately reweighed and the total water uptake is determined. Simple immersion tests in water for 24 h (ASTM D570) can be used to assess if polymers have a tendency to undergo hydrolysis in moist environments. However, the shortcoming of the 24 h test is that the time can be well short of the time required for the polymer to reach its equilibrium water content. For some polymers this can take many weeks and is strongly dependent on the sample geometry of the polymer [19,20].

It is well known that polymers are subject to degradations due to exposure to heat, moisture, chemicals and UV light. When a polymer is exposed to an environment capable of causing degradation, chain scission and cross-linking can occur, causing changes in molecular weight. In addition, degradation can result in a change in the appearance of a polymer or the chemical composition. Water absorption can also change the macroscopic mechanical behaviour of the materials. When water is absorbed, there is increased mobility of the polymer chains, resulting in lower strength and increased creep [21].

2. Experimental

2.1. Materials

In this study, 40 × 40 × 40 mm cube middle density PE specimens were used. The screws were inserted into center of the surface on the polyethylene cube (Fig. 1). The photograph of the screw is depicted in Fig. 2. The minor diameter of the screw was 3.52 mm and the major diameter was 4.7 mm. The screw head diameter was 9.3 mm.

2.2. Experimental apparatus

Pullout tests were carried out on an INSTRON 4411 test machine. As shown in Fig. 3b, a home made screw holding apparatus was designed and used during the studies. The holding apparatus and specimens are shown in Fig. 3.

![Fig. 1. Screwed polyethylene specimen.](image)
In this study, pullout strength of screw in the polyethylene exposed to different environmental conditions was examined. Holes were prepared by pilot drilling to minor diameter of the screw on each polyethylene specimen. The screws were fully inserted. Five groups of specimens with each group having a five specimens were kept in the closed glass container under different environmental conditions for one month: the first group was immersed in the water at 20°C, the second group was immersed into water at glass container in the oven at 60°C, the third group was immersed in the water saturated with NaCl at 20°C, the fourth group was immersed in the water saturated with NaCl in the oven at 60°C, the fifth group was in the oven at 60°C. Pullout tests were performed under ambient room conditions with 5 mm/min tensile speed.

Four groups of polyethylene specimens were immersed in the water for one month. After this period the specimens were wiped with towel and then weighed with precise balance. The measured specimens’ weights were compared with that of the original specimen determined a weight gain at all specimens because of the water absorption. Details of the amount of water absorption of polyethylene specimens that were immersed in the water are given in Table 2. As is mentioned in the literature, the water absorption of polyethylene is around 0.01% at 24 h [22]. Due to immersion time being a month, water absorption of specimens is higher than 0.01%.

3. Test results and discussion

3.1. Effect of different environmental conditions on screw pullout strength

Screwed specimens under ambient room were exposed to different environmental conditions and tested and their pullout performances are given in Fig. 4.

Screw pullout performance of the specimens immersed in water at different conditions was higher than other specimens. Screw pullout strength (SPOS) of the specimens

<table>
<thead>
<tr>
<th>Specimen groups</th>
<th>Mean weight before immersion in water (gr)</th>
<th>Mean weight after immersion in water (gr)</th>
<th>Water absorption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immersed in water at 20°C</td>
<td>74.5512</td>
<td>74.5659</td>
<td>0.02</td>
</tr>
<tr>
<td>Immersed in water saturated with NaCl at 20°C</td>
<td>78.6627</td>
<td>78.6853</td>
<td>0.03</td>
</tr>
<tr>
<td>Immersed in water at 60°C</td>
<td>73.224</td>
<td>73.2468</td>
<td>0.03</td>
</tr>
<tr>
<td>Immersed in water saturated with NaCl at 60°C</td>
<td>70.6494</td>
<td>70.6769</td>
<td>0.04</td>
</tr>
</tbody>
</table>
immersed in water at 20 °C had the highest peak. SPOS of the specimens immersed in water at 20 °C was higher than the specimens immersed in water saturated with NaCl at 20 °C. If we compare these two groups of test results, it can be seen that the pullout strength of specimens immersed in water saturated with NaCl decreased approximately % 2 due to NaCl. In Fig. 4, it is shown that screw pullout resistance of specimens immersed in water at 60 °C is higher than screw pullout resistance specimen in the oven at 60 °C, immersed in water saturated with NaCl at 60 °C and in ambient room conditions. Screw pullout strength of specimens under ambient room conditions was less than that of specimens immersed in water at 20 °C, immersed in water saturated with NaCl at 20 °C and immersed in water at 60 °C. It is shown in Table 2 all that specimens had weight increase when immersed in water. Fastening was more tight due to swelling. For that reason screw pullout strength of a specimen increased when it absorbed water.

It is observed that increasing the environment temperature results in decreasing the screw pullout strength of specimens (Fig. 4). The screw pullout strength of specimens immersed in water at 20 °C was higher than that of specimens immersed in water at 60 °C and also at saturated NaCl conditions. The lowest screw pullout strength was seen in the specimen placed in the oven at 60 °C, as screw and polyethylene specimen had different cooling rates, and fastening was loosening with elevated temperature [11].

A comparison of the yield energy of specimens under ambient room conditions with those kept in various environmental conditions is made with block diagrams, which is shown in Fig. 5. In Fig. 6 their fracture energy comparison is depicted with block diagrams.

According to the results of the experiments, the specimens immersed in water at 20 °C had higher yield energy than others. From Fig. 5 it can be stated that the specimens immersed in water at 60 °C had higher yield energy when compared to the ones immersed in saturated salt or the ones kept in an oven in a closed glass container. As it is seen in Fig. 5, NaCl decreased yield energy of the specimens in screw pullout tests. The specimens in ambient room conditions have lower screw pullout yield energy than all specimens immersed in water at 20 °C, immersed in water saturated with NaCl at 20 °C and immersed in water at 60 °C. The lowest yield energy of the specimen was measured at specimen in the oven at 60 °C.

Similar to the test result in Fig. 5, the specimens immersed in water at 20 °C had the highest fracture energy (Fig. 6). Also, the fracture energy of specimens immersed in water at 60 °C was higher than that of other specimen groups. Saturated NaCl water and increasing ambient temperature decreased screw pullout performance. For that reason, the fracture energy of these specimens was low. In Fig. 6, it is seen that fracture energy of specimens in ambient room conditions is lower than the ones immersed in water.

Although the specimens that were immersed in water at 60 °C had a very close pullout strength in comparison to the ones immersed in water saturated with NaCl at 20 °C, they had higher yield and fracture energy.

In Fig. 7, the effect of the environmental conditions on displacement is shown. Displacement of all specimens was placed in the range of 1.78–1.93 mm. The specimens immersed in water had the highest displacement. The effect of temperature and water on displacement was lower than the effect of other properties. The environmental effect on yield and fracture energy was similar.
3.2. Effect of application thermal cycle on the specimens screw pullout strength

The mechanical performance of threaded components, and of the assemblies in which they are used is effected by many properties such as axial or tensile strength, torsional strength, shear strength, resistance to vibration loosening, fatigue resistance, resistance to thermal cycling, and hydraulic pressure integrity [22]. In this study, thermal cycling was applied to 20 polyethylene cubic specimens (four groups). All samples drilled to 3.6 mm diameter and 23 mm depth of pilot hole and screwed with a screw are shown in Fig. 2. Thermal cycling was performed in a self-designed apparatus composed of two separate tanks consisting of boiling water tank and an ice-water tank. The temperature was kept at 100 °C for the boiling tank and 0 °C for the ice-water tank. The specimens were placed into the sample holder and immersed into the first chamber. After waiting for 1 min in boiling water, the sample holder was raised from the first tank and immersed quickly into the second tank, which was full of ice-water. After waiting for 1 min in ice-water, the samples were immersed back into the boiling water. This operation took 2 min totally and corresponded to one thermal cycle. After the 5th, 15th, 30th and 90th thermal cycles, five test samples were collected from the sample holder. After being carefully dried, screw pullout tests were carried out on each sample. Pullout tests were conducted under ambient room conditions with 5 mm/min speed. Five samples were tested for each thermal cycle group and the average value of five samples is given in Table 3.

In Fig. 8, displacement and load graphs of specimens obtained after INSTRON 4411 instrument testing and thermal cycle application 5, 15, 30, and 90 times are depicted. As seen in Table 3, the maximum load values of 4.46 kN were obtained with five thermal cycles, 4.1 kN with 15 thermal cycles, 4.49 kN with 30 thermal cycles and 3.97 kN with 90 thermal cycles.

Specimens were weighed with a precise balance, and hardness was measured using CV instruments shore scale D durometer before thermal cycles and after thermal cycles. Details of weight and hardness difference of specimens due to thermal cycles are given in Table 4. As shown in Table 4, water absorption decreased in the specimens in direct relation with the number of thermal cycles. Weight gain of specimens decreased with increasing thermal cycle number, specimen hardness after 15 thermal cycles it decreased but after 30 thermal cycles increased to the initial thermal cycle hardness. Specimens on which 90 thermal cycles were applied had the lowest hardness.

Increase in thermal cycle has yielded load values that increased initially, which increased and finally decreased again. Load values initially arose from swelling, and fastening was more tight with water absorption but later at high thermal cycles the number of load values decreased due to increasing temperature effect (in boiling tank at 100 °C). In other words, as the number of thermal cycles increase, initially pullout strength decreases due to heat, then an increase in pullout strength is observed due to swelling caused by immersion in water. Finally an increase in thermal cycle number decreases pullout once again. As can be seen in Table 4, hardness values are directly related to screw pullout resistance.

Among the specimens with thermal cycle application, in those with 90 thermal cycles the effect of thermal cycle on screw pullout performance was clearly apparent. In Table 5, comparison of the specimens with 90 thermal cycles with original sample (having no thermal cycle application) regarding pullout resistance is made.
From Table 5 it can be understood that the original sample application had higher screw pullout strength when compared to those with 90 thermal cycle applications. Also it can be stated that different cooling rates of polyethylene and screw resulted in a decrease of pullout resistance in the specimens with 90 thermal cycles application.

4. Conclusions

(1) The influence of different environmental conditions on pullout strength of screwed polyethylene was investigated. It was known that water absorption caused loss of strength and stiffness. Surprisingly, according to the test results, screw pullout performance increased when immersed in water. Besides, screw pullout strength of specimens immersed in saturated NaCl water was lower than those immersed in water; the pullout strength of screwed polyethylene decreased at elevated temperature.

(2) Although medium density polyethylene had very little water absorption capacity (0.01%) in 24 h, the water gain of all specimens immersed in water and saturated NaCl water was measured approximately as 0.02%–0.04% after one month. Threaded fasteners had a lot of cracks and grooves and these increased water absorption. Threaded fasteners of polyethylene specimens were more tight because of the swelling effect. Especially, screw pullout strength of specimens immersed in water at 20 °C was higher than the other specimens. Also, they yielded higher energy and fracture energy than that of others. Because water absorption specimens immersed in water saturated with NaCl at 20 °C and specimens immersed in water saturated with NaCl at 60 °C was little higher than those of specimens immersed in water at saturated NaCl at 60 °C conditions. Because of high temperature and chemical attack effect, pullout performance of the specimens immersed in water at saturated NaCl at 60 °C was decreased (Fig. 5). Lowest screw pullout strength was seen in the specimen kept in the oven at 60 °C. Similarly, yield energy and fracture energy of those was lower than the others (Figs. 5–7). Threaded fastening was loosening with elevated temperature and these specimens pullout performance has been decreased. Also screw and polyethylene specimen have different cooling rates due to which fastening was loosening.

(3) The stress crack resistance of polyethylene generally decreases with high temperatures [22]. Screw pullout strength of specimens immersed in water at 60 °C was little higher than those of specimens immersed in water at saturated NaCl at 60 °C conditions. Because of high temperature and chemical attack effect, pullout performance of the specimens immersed in water saturated NaCl at 60 °C was decreased (Fig. 5). Lowest screw pullout strength was seen in the specimen kept in the oven at 60 °C. Similarly, yield energy and fracture energy of those was lower than the others (Figs. 5–7). Threaded fastening was loosening with elevated temperature and these specimens pullout performance has been decreased. Also screw and polyethylene specimen have different cooling rates due to which fastening was loosening.

(4) In thermal cycling application, water absorption increased the pullout performance and also temperature difference decreased the screw pullout strength. For that reason, after five thermal cycles the maximum load was increased according to the original sample, but the pullout strength of exposed 15 thermal cycles was decreased, then after 30 thermal cycles maximum load increased again and finally after 90 thermal cycles the pullout performance decreased (Fig. 8, Tables 3 and 5). Initially, threaded fasteners increased water absorption by cracks and grooves and it was shown that 0.01% weight gain was measured in 5 and 15 thermal cycles application specimens. In high thermal cycle numbers, weight gain was not measured. The measured hardness of specimens was shown to be similar in dispersion with pullout performance specimens (Table 4, Fig. 8).

(5) The original sample had higher screw pullout strength when compared to those with 90 thermal cycle applications (Table 5). It can be stated that the different cooling rates of polyethylene and screw resulted in a decrease of pullout resistance in the specimens with 90 thermal cycles application. Also, with increased number of thermal cycles, the effect of different temperatures on pullout strength is increased.

<table>
<thead>
<tr>
<th>Specimens</th>
<th>Hardness before thermal cycles (shore D)</th>
<th>Hardness after thermal cycles (shore D)</th>
<th>Mean weight before thermal cycles (gr)</th>
<th>Mean weight after thermal cycles (gr)</th>
<th>Water absorption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 thermal cycles</td>
<td>68</td>
<td>68.5</td>
<td>74.445</td>
<td>74.4535</td>
<td>0.01</td>
</tr>
<tr>
<td>15 thermal cycles</td>
<td>68</td>
<td>66.85</td>
<td>73.456</td>
<td>73.4617</td>
<td>0.01</td>
</tr>
<tr>
<td>30 thermal cycles</td>
<td>68</td>
<td>68.8</td>
<td>73.1352</td>
<td>73.1354</td>
<td>0.00</td>
</tr>
<tr>
<td>90 thermal cycles</td>
<td>68</td>
<td>66</td>
<td>82.5423</td>
<td>82.5409</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specimens</th>
<th>Maximum displacement (mm)</th>
<th>Maximum load (kN)</th>
<th>Yield energy (J)</th>
<th>Energy break (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original sample</td>
<td>1.78</td>
<td>4.32</td>
<td>4.84</td>
<td>9.66</td>
</tr>
<tr>
<td>90 thermal cycles</td>
<td>1.80</td>
<td>3.97</td>
<td>5.40</td>
<td>10.64</td>
</tr>
</tbody>
</table>

Table 4
Changes in hardness and weight of specimens with thermal cycles application

Table 5
Comparison of specimens with 90 thermal cycles with original sample

From Table 5 it can be understood that the original sample application had higher screw pullout strength when compared to those with 90 thermal cycle applications. Also it can be stated that different cooling rates of polyethylene and screw resulted in a decrease of pullout resistance in the specimens with 90 thermal cycles application.
Today, polyethylene has a wide range of uses in industrial applications. Polyethylene and the other polymers are joined with adhesive bonding, welding, and mechanical fastening. As can be seen from the previous studies, mechanical fastening must be preferred when joining polyethylene parts which are to be used in water or humidity environment conditions, as water absorption increases the screw pullout strength. Screw pullout strength decreased with chemical corrosion and elevated temperature, but the effect of these factors on other joint performance was higher than threaded fasteners. For that reason, threaded fastening was preferred under these conditions. Although thermal cycling effect on screw pullout strength is negligible especially in low application numbers, at high thermal cycling application, pullout strength is decreased.

References