Using Screws to Fasten into Plastic

by Laurence Claus

Very early in my career I worked on a very interesting project. In the U.S. after a new car is assembled, it is either loaded into a truck or onto a train for delivery. In this case, our customer's new model vehicle was loaded onto a train car for shipment across the country. When it arrived on the other end of its journey the cars would not start and could not be offloaded. It did not take long to discover that the glove box doors were opening in route, causing the glove box light to come on, and the battery to drain down. When the root cause of this problem was investigated it was quickly determined that the plastic ABS bosses which accepted the screws that held the glove box door assembly together were completely cracked and broken. The Type AB screws that had been used exerted so much radial stress on the plastic ABS bosses that they had destroyed them causing the plastic to fall away, the doors to flop open, and the new cars to arrive in an inoperable state.

This is but one of thousands of similar stories of fastening in plastics that have gone horribly wrong. Perhaps like no other commonly used material, there are hundreds of varieties of plastics spanning an even broader range of performance characteristics. This makes it difficult, if not impossible, to develop a "one size fits all" fastening strategy, which is the normal way most fastened joints are designed.

The use of plastics in everyday products is a relatively recent development. Although some of the first serious uses of plastics were during World War II, it really wasn't until the last forty years that use of plastics in everyday products dramatically accelerated. As with any technology evolution, to propel the fundamental technology other enabling technologies needed to be developed. This was particularly true of ways to fasten plastic. Unfortunately, early methods of fastening plastics used the available technology, which was often flawed for this type of application and resulted, in the best cases, poor performance and, the worst cases, failures and scrap. For these reasons thread forming fasteners would take a long time to catch on and become accepted as a viable way of fastening plastic components.

Fundamentals of Plastics

To understand why fastening into plastics is challenging, one must possess some basic knowledge of Material Science. Plastics describe a wide range of materials comprised of repeating molecules that form long chains known as polymers. These polymers can fall into three general categories; thermoplastics, elastomers, and thermosets, all exhibiting very different properties and performance characteristics. Thermoplastics are made up of straight and slightly branched molecule chains so that they may be reheated and used multiple times. Thermoplastics tend to be less strong than thermosets but much more flexible. Thermosets contain highly crosslinked molecules that form rigid materials that cannot be heated up and re-melted.

When thermoplastics cool from their melted state, some crystallize and some do not. The ones that form crystalline structures upon cooling do not do so perfectly and are more correctly described as semi-crystalline thermoplastics. Several common examples of semi-crystalline thermoplastics are polyethylene, polypropylene, and nylon. Thermoplastics that do not form semi-crystalline structures are known as amorphous plastics. These materials are sometimes described as polymer glasses. The most significant characteristic of these amorphous materials, however, is their limited capacity to accept stress. In other words, they can be very sensitive to any form of applied stress. Several common examples of this type of plastic are polycarbonate, ABS, and PMMA (Plexiglass).

Understanding the differences between amorphous plastics, semi-crystalline plastics, and thermosets is extremely important for the fastener engineer because it can determine whether a plastic boss will be prone to cracking, chipping, or "white marks" when a screw is fastened into it.

Other properties of the plastic may also be important to understand. For instance, the Flexural Modulus, or measure of the plastic's stiffness is important when designing the plastic boss used to accept the threaded screw. In a similar manner, molecular weight of the plastic and whether the base plastic has added filling such as glass or mica can strongly influence how a plastic joint is properly designed.

In summary, it is critical for the designer or fastener engineer to understand the underlying type and properties of plastic that is intended to be fastened into with a threaded fastener. Unlike certain metal materials, which exhibit many common properties, no two plastics behave exactly alike. In fact, some plastics are so dramatically different from one another that it makes a "one-size-fits all" approach to using threaded fasteners risky or downright impossible.

Fasteners for Thermoplastics

The first screws used in thermoplastics were, most likely, wood screws. The reason for this is simple, at the time they were the only option around. The problem, however, is that wood screws are not very precise and have wide thread profiles. Needless to say, they did not work well. This lead to a wide variety of derivative screws being used. Eventually choices would narrow down to thread cutting choices and, for thread forming choices, HiLo®, Plastite®, and Type AB screws.

Each of these choices has drawbacks. Thread cutting screws create debris and have widely variant assembly characteristics. We know today that they do not provide good fastening solutions for thermoplastics. The HiLo® has inconsistent and often poor assembly characteristics and may be more prone to self-loosening than other similar thread forms. Plastite's® are a derivative of lobular shaped thread rolling screws for mild steel. Of all the choices, this may be the most risky, as the lobular shape very specifically imparts stress concentrations at the lobes. While this phenomenon has advantages when thread forming into mild steel it may be downright catastrophic with amorphous plastics. Type AB (or sheet metal) screws impart large radial stresses which either results in cracked bosses or the need to use significantly more plastic to beef up the circumference of the plastic boss.

It would not be until the early 1980s that a company, EJOT Verbingdunstechnik, would put pen to a clean sheet of paper to develop the optimum screw design for fastening into thermoplastics. The result was the first generation PT® screw. This design incorporated a "knifelike" thread profile to reduce radial stresses exerted on the boss, an optimum pitch to prevent self-loosening, and a root diameter relief to allow material to flow unimpeded. In the late 1990s the second generation of PT® screws, the Delta PT®, would be released and provide improvements over the original. In particular, the thread profile would be adjusted to reduce the risk of material flow stagnation and increase the benefits of a "knife-like" profile. Additionally the recessed root would still provide ample space for material to flow and the core diameter was increased to provide greater screw strength in higher flexural modulus materials. Heads were designed to produce the maximum bearing surface possible and through hardening replaced case hardening to reduce hydrogen embrittlement risks.

Since the introduction of the PT® almost forty years ago, other designs have come on the market which address some of the properties and characteristics unique to plastics. None of these other screws embody as much thought or technology as the Delta PT® screw, but collectively this "body" of options replaces the early and less than optimum performing designs, which has renewed a confidence in users that thread forming is both feasible and best practice.

How Thread Forming Works

It really doesn't matter what material one is thread forming into, as the science of thread forming is pretty much the same. Figure 1 illustrates a typical thread forming application. As a thread is driven into a boss, the amount of torque that is required to advance the screw steadily increases. However, as the figure illustrates the most significant increase in the torque early in the cycle comes in the first moments as the first thread is formed (Point 1). This is known as the Thread Forming Torque. In theory, the next thread and the next one and so on will possess this same thread forming torque. Therefore, subsequent spikes in torque during the driving phase of the screw don't exist. Friction from contact with the newly formed threads, however, does exist and builds as each new thread is created and more and more of the screw thread comes in contact with the plastic material. This is evident in Figure 1 as the torque continues to rise after the initial thread forming torque is generated at a steady and consistent, linear rate.

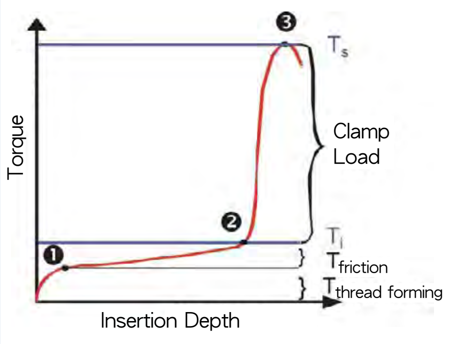

Figure 1: Typical Torque versus Time Progression of a Thread Forming Screw

When the screw head just comes into contact with the material that is going to be clamped, the "driving" phase of the process is complete and the measured torque at Point 2 represents the value usually referred to as the "Driving Torque". At this point continued turning of the screw results in the joint beginning to be compressed as a clamp load is generated. This is represented on the Torque versus Time graph by a nearly vertical rise in torque. Bearing in mind that the strength of the screw is magnitudes greater than the plastic strength, the plastic material is eventually overloaded and the internal plastic threads shear (or strip) from the boss (Point 3). This is often referred to as the "Stripping Torque" or "Ultimate Failure Torque".

These values are extremely important to the fastener engineer. Engineers and designers will conduct multiple iterations of this test to obtain statistical data from which they can infer a maximum driving torque and minimum stripping torque. Once they have these values in hand, they can develop a recommended Tightening Torque (torque used by the installer to set the screw) for the joint that will allow safe and consistent assembly.

Other Considerations

Perhaps the most important consideration of all, but one that is often overlooked, is the ability of the joint to retain a clamp load. Without a clamp load the joint is "loose" and vulnerable to self-loosening. It will also allow the intended clamped members to move, producing unwanted squeaks, rattles, or joint failure. Therefore, understanding the stress relaxation behavior is important. For plastics, addressing this issue is often counterintuitive to what we have come to learn from traditional fastener engineering know-how. The traditional way of thinking about a bolted joint is that the more preload (amount of stretch in the bolt) we generate, the better. In the same way that preload is normally increased with increasing torque, it is true that in a plastic joint one is able to obtain increasing loads with higher torque. However, we have to revisit our knowledge of plastics and our understanding that plastics do not like stress. The more stress that a plastic is exposed to or the more highly concentrated the stress, the more the plastic will want to relax. Therefore, higher clamp loads may actually work against us, since the material will relax more than it would with a lower clamp load, in some cases resulting in so much relaxation that all clamp load is lost. In response, proper fastener engineering often means recommending a lower torque so that the relaxation is kept in-check and clamp load is not entirely lost.

Drive speed is also an important value to regulate. The higher the driving speed the more friction and heat that is created during installation. In some of the less engineered plastics this heat can sufficiently lessen the mechanical performance of the plastic and result in lower ultimate failure torque. Although it is tempting for many assemblers to increase the drive speed as high as possible, normally five hundred rpms or less is recommended.

Design optimization is very important. Using the correct pilot hole size, thread engagement, and counterbore size and depth are all critical to obtaining the best possible performance out of the joint. A common error, and one that should be avoided, is believing that a joint designed for one screw type will perform equally well with a different screw type. Designers and end users should be made aware of this in the event that they are entertaining a change in screw types.

Conclusion

As is probably evident from the article above, thread forming into plastic bosses is no trivial undertaking. In fact, it requires a great deal of expertise and knowledge of how different plastic materials behave. Treating all plastics as equivalents is a sure equation for problems and potential failures. Those that manufacture and sell these types of products should have individuals that are educated in thread forming and in plastics so that they can assist the end user with the best design assistance possible.