

STAKING PLASTIC WITH INFRARED LIGHT

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Abstract

Even before Boothroyd and Dewhurst made Design for Manufacture and Assembly (DFMA) popular in 1983, engineers were searching for ways to eliminate fasteners and adhesives in plastic part assemblies. With that goal in mind, it's no surprise that forming (staking) an integral plastic stud (boss) in order to retain another component has become a common practice in the manufacturing industry. The patented InfraStake[®] process (1) is a relatively new alternative to conventional staking methods. As the name suggests, the energy source is infrared light. The InfraStake module clamps the parts together, evenly heats the stud with precisely directed infrared light, and forms the plastic with a low-force pneumatic cylinder and a non-heated punch. Figure A shows a typical InfraStake module.



Figure A – InfraStake Module

Introduction

There are several established methods for staking plastic parts. These methods can typically be used for any type of thermoplastic. Some of the more common materials that are staked include polyethylene, polypropylene, ABS, polycarbonate, acetal, and polyamide. The process also works with plastics that contain fillers such as glass or talc. While certain plastics can actually be cold-formed if the studs are small enough, it is far more common to heat the plastic and then form it with a shaped tool. Depending on the technology, this tool can be a rigid punch or a vibrating horn/sonotrode.

The traditional methods include:

- Hot air staking
- Thermal staking (heated punch)
- Ultrasonic staking

Although these processes all melt and form plastic, they each do it in a unique manner. As a result, each has inherent strengths and weaknesses when it comes to minimizing cycle time and producing parts with acceptable joint strength. The struggle to overcome the weaknesses ultimately led to the development of the InfraStake product as an alternative staking technology. This paper provides an explanation of how the InfraStake process works and how it can be used to address the challenges associated with staking plastic parts. Because the infrared staking process is relatively new, no other Society of Plastics Engineers literature on the subject was found.

Anatomy of an InfraStake Module

As shown in the exploded view in Figure B, the InfraStake module has several different components. The punch cylinder assembly consists of a double-acting pneumatic cylinder with a magnet attached to the end of the cylinder rod. The magnet connects the cylinder to the punch assembly. An aluminum mounting adapter with a tapped hole in the center is attached to the back of the cylinder. This adapter is used to attach the InfraStake module to a tooling plate or other mounting surface.

The InfraStake body is an aluminum cylinder that has an integral power cable internally wired to two spring-loaded electrical contact plungers. These plungers provide the electrical connection to the lamp assembly and allow it to be easily removed from the module. The body also has an air fitting where the cooling air enters. The lamp assembly is attached to the back of the reflector, which surrounds the lamp and directs the infrared energy. The punch assembly extends through machined guide holes in the reflector. The ends of the punch are clamped into the aptly-named punch coupler which connects to the punch cylinder magnet. The final component, the concentrator, focuses the infrared energy on the boss. It slips over the end of the InfraStake body and is locked in

place by rotating it slightly to engage a dowel pin in the body with its machined hook feature.

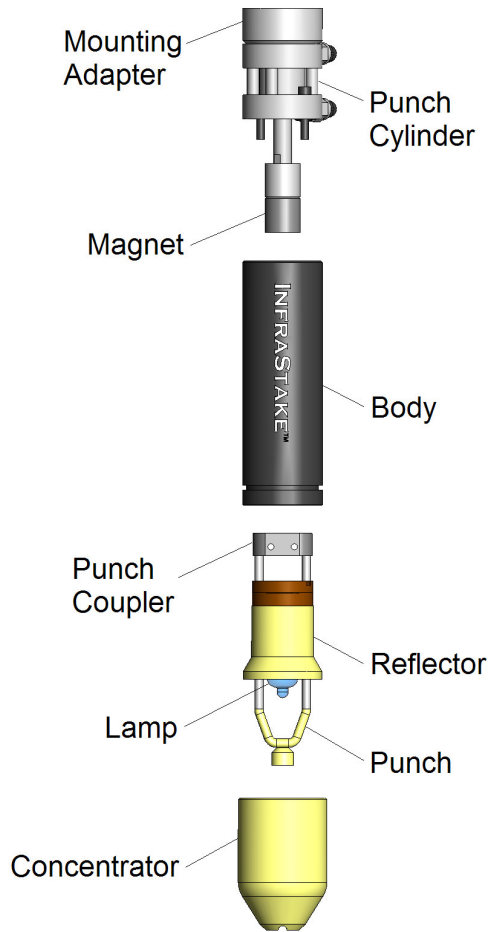


Figure B – Exploded View

The overall design allows the module to be quickly disassembled without tools. Once the concentrator is removed, the lamp, reflector, and punch assembly can be removed by pulling the punch straight down to disengage it from the magnet.

Process Overview

The InfraStake process can be broken down into four basic steps:

1. Clamping
2. Heating
3. Forming
4. Retracting

In the most general terms, these steps are the same for each of the different staking technologies. However, when

they are examined in detail, there are some significant differences in both the methods and their effectiveness.

Clamping

One of the first challenges when staking plastic parts together is making certain that they are properly assembled. Industry experts have discovered that plastics are materials that are not always known for their dimensional stability. As a result, producing dimensionally-stable plastic parts is a common challenge, and it is often necessary to assemble plastic components that are at least slightly warped. Unfortunately, we do not inhabit the perfect world where actual parts always match the CAD models and there is no variation from one group of molded parts to the next. An assembly process that can compensate for a relatively high degree of part variation can offer a real advantage.

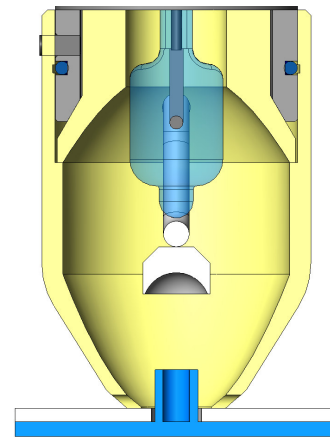


Figure C – Clamping

With conventional staking methods, the parts can be clamped together near a stake point, but generally not directly at the stake point. Consequently, if there is a gap between the parts, the lower portion of the boss can be obstructed by the mating part, making it difficult to heat the entire length of the boss. The InfraStake process clamps the parts together directly at the stake point (Figure C), ensuring that they are held together properly throughout the entire cycle. When the InfraStake module is in position over the parts, the concentrator makes direct contact with the upper part, clamping it to the lower part and holding them both in the proper position. As an added benefit, because the parts are ideally clamped together at the stake points, secondary part clamps are not necessary.

Heating

After the parts have been clamped together, the boss must be heated. This is the heart of the process, and it is

one of the areas where InfraStake is significantly different than conventional staking technologies. The energy source used in the InfraStake process is a 12-Volt, 100-Watt, technical-grade, halogen lamp, not unlike those used in many automotive fog lamps. Although the lamp emits both visible and infrared light, it is the infrared energy that actually heats the plastic. The process works with materials of all different colors and transparencies, with dark, opaque materials typically requiring less heat time. As the lamp is energized, the reflector directs the infrared energy from the filament into a column around the punch. This column of energy travels downward until it is focused on the full perimeter of the boss, heating it from top to bottom. To make this possible, the reflective surface geometry of both the reflector and the concentrator creates a focal area that is centered on the boss.

As seen in Figure D, the InfraStake module transfers the infrared energy from the lamp to the boss through radiation. However, unlike the type of radiation used in medical x-rays, the operator of an InfraStake machine does not need to wear a stylish lead apron while operating the machine to prevent damage to vital organs. Although the infrared energy is tightly-focused, it is not as powerful as an industrial laser, and does not pose the same safety risks (it also does not warrant the same type of intimidating warning labels). Because the InfraStake module completely encapsulates the working area, there is no possible way to access the area where the infrared energy is being focused once the cycle has begun. Even in situations where the operator can contact the InfraStake module during the staking process, the outer surface of the module stays cool to the touch and completely safe. This is possible because the reflective surfaces are plated with gold, which, in addition to enhancing the aesthetics of the outside of the module, allows the reflector and concentrator to reflect almost all of the infrared energy emitted by the lamp. This prevents the InfraStake module and the surrounding area from being heated and also improves the efficiency of the system by directing as much of the infrared energy as possible toward the boss. With the burn risk eliminated, not only will the operator be less paranoid, but a simple press mechanism can be used on machines that would otherwise require heavy guarding, a shuttle, or a turntable for protection.

Ideally, the boss would be heated as quickly and as evenly as possible. Realistically, each technology is limited to some extent by the type of heat transfer mechanism used in the heating process. A heated punch transfers energy by conduction at the point where it contacts the boss. As a result, the plastic at the top of the boss is heated more than the plastic at the bottom because it spends more time in contact with the heated tool. In ultrasonic staking, the vibrating tool contacts the boss in the same way, at the top. Although the ultrasonic energy

can heat some of the plastic beyond the contact point, the top of the boss still receives more energy than the bottom. On the other hand, because the ultrasonic waves travel through the plastic part, some of the energy can reach (and possibly damage) the show surface opposite the boss. In some instances, excessive amplitude can also damage or fracture the boss at the base. Some hot air systems have a single outlet, usually angled toward one side of the boss. Inevitably, one side receives more heat than the other. However, even if the hot air nozzle surrounds the boss, the plastic can't absorb all of the heat from the hot air. Consequently, much of the heat energy is wasted as it blows right past the boss. Unfortunately, the area beyond the boss often involves part features that are much more durable at room temperature and could be damaged by the stray heat. This can be particularly true when staking printed circuit boards to plastic housings.

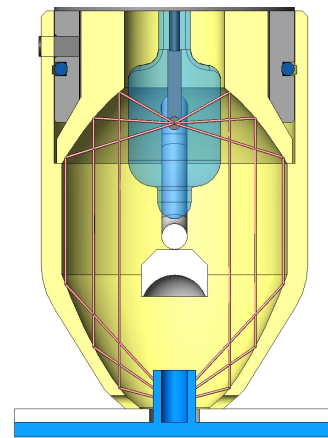


Figure D – Heating

One way to address these issues would be to improve the heat transfer properties of many common thermoplastics. However, since that would be expensive and very difficult to accomplish, the InfraStake process instead addresses them by surrounding the boss with the concentrator and reflector details. This arrangement heats the boss uniformly, without overheating any particular area, until the plastic reaches a semi-molten state. Because the concentrator surrounds the boss, the energy is focused and contained there and does not affect other areas of the plastic part. The controlled environment also prevents the process from being affected by changes in the ambient temperature. This prevents damage to adjacent part features by controlling where the infrared energy can go. The infrared energy is focused only on the portion of the boss that extends through the mating part, so there is also very little chance of affecting the plastic on the show surface opposite the boss. Although the round profile works for many different boss shapes the reflective surface geometry can be tailored, if necessary, to a non-circular boss. Blade or tab stakes are good examples of this.

The ability to focus the infrared energy precisely where it is needed also minimizes the power required by the process. Unlike a typical hot-air system which uses a 400-Watt heater for each stake point, an InfraStake module uses only a 100-Watt lamp. Since electricity prices haven't been going down, this has a real impact on the operating costs of the equipment. Additionally, since the system does not have any internal components that have to 'warm up' before use, no preheating is necessary.

The process parameters for the heating portion of the InfraStake cycle are quite simple. The lamp is either on or off, and the amount of infrared energy transferred to the boss is determined by the amount of time that the lamp is on. The other parameter that affects the heat cycle is the cooling air flow rate. A small amount of cooling air flows through the InfraStake module during the staking cycle for several reasons. It keeps the lamp from overheating inside the module and it maintains positive pressure in the area surrounding the polished reflective surfaces. Positive pressure keeps the surfaces clean by keeping out any dust or airborne contaminants. The cooling air also helps to regulate the surface temperature of the boss to prevent overheating. Finally, the air flow keeps the punch relatively cool so it can effectively remove the heat from the plastic once it makes contact with the boss.

When heating thick sections or staking materials that off-gas (smoke) easily, the lamp can be pulsed on and off to regulate the surface temperature of the plastic and prevent material degradation from overheating. As with other staking technologies, the cycle time required to properly heat the boss can be reduced by minimizing the amount of plastic that must be heated. For this reason, bosses over 3 mm (0.125 inch) in diameter should be made hollow to eliminate the thick cross section that would otherwise exist in the center. An added benefit of this practice is that it helps to eliminate sink marks from molding on the show surface of the part.

Process control is important for almost any plastic joining method. The InfraStake controllers error-proof the process by monitoring the current draw of each module during the heat cycle and alerting the operator if there is a problem.

Forming

Although forming the plastic (Figure E) may seem like the easy part of the cycle, there are still a number of factors that must be considered. Most manufacturers are not looking for ways to add time to their assembly processes, so the plastic should be formed as quickly as possible. As soon as the boss is heated, the lamp is turned off and the punch is extended. The punch is driven by a small-bore pneumatic cylinder with a stroke length that is

based on the height of the boss. Because the plastic doesn't require much force to form once it is heated to a semi-molten state, very little force is transferred into the rest of the part, minimizing the chance of damage to the show surface.

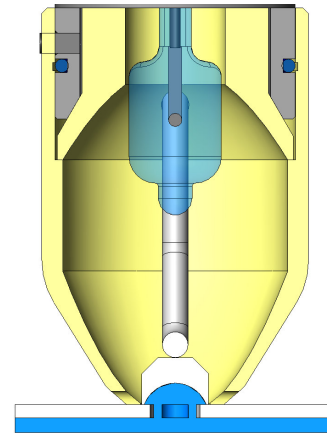


Figure E – Forming

It is important to control where the plastic goes while forming the stake. Consequently, the punch cavity is designed to match the volume of plastic in the unstaked boss. This ensures that the stake is fully formed while also minimizing the amount of plastic that is not captured within the punch cavity. The punches, made of steel, are machined, polished, and gold-plated. The gold plating and the location of the punch (outside of the focal point of the reflective surfaces) keep it at a reasonable temperature so it can draw the heat out of the molten plastic quickly. The air flow through the InfraStake module also assists in regulating the punch temperature which prevents the plastic from sticking to it. When staking glass-filled materials, which can be abrasive, the punch detail is often machined from A2 tool steel, which is hardened to resist the abrasion (this should not be confused with A1, which is steak sauce, and did not perform nearly as well in testing).

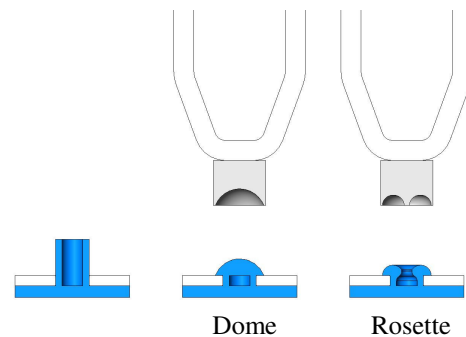


Figure F – Dome and Rosette Punch Designs

There are several different geometries that can be used for the punch cavity. For round bosses, the dome style and the rosette style are very common (Figure F). Pull tests performed at Extol, Incorporated have shown that the strength is actually very comparable between the two styles. In fact, the diameter of the clearance hole in the mating part often has a much more significant affect on joint strength than the punch geometry. Rectangular shapes can also be used when staking features such as tabs. The dome punch design minimizes the distance that the plastic must be displaced, and the lack of a center pilot reduces its sensitivity to bosses that are slightly off-center. As a result, it can often provide a larger process window than a rosette design.

The InfraStake body has two integral tracks that accept proximity sensors triggered by the position of the punch coupler magnet. These sensors can be used to verify that a boss is present before the cycle and to verify that the punch has extended completely at the end of each cycle.

Retracting

The final step in the InfraStake cycle is to retract the punch (Figure G). At this point, it is important that the plastic has resolidified to the point where it can maintain its shape and structure. If it does not, the stake joint may loosen. Also, if the plastic has not cooled sufficiently, it may stick to the punch. This can pull some of the plastic off the formed boss, compromising its strength. The InfraStake concentrator functions as a stripper plate, holding the part down and preventing it from lifting as the punch retracts. The InfraStake module is only removed from the part after the punch has retracted from the staked boss.

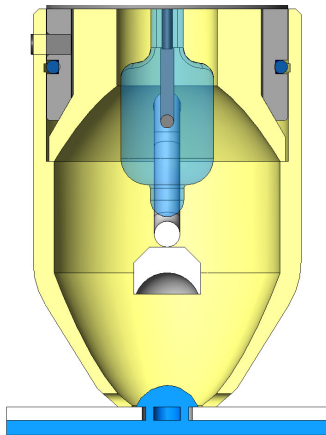


Figure G – Retracting

Boss Sizes

The InfraStake process can be used to stake bosses of many different sizes. The IS125 model, which is the most popular size, is 31 mm (1.25 inches) in diameter at the concentrator. Due to recent design improvements, it can now stake bosses up to 8 mm (0.313 inch) in diameter and up to 12 mm (0.5 inch) tall. There are two other standard modules, the IS170 and the IS230, which can stake larger bosses, but those applications are far less common than the smaller sizes.

The typical boss sizes can produce very strong stakes. In a group of ten 6 mm (0.25 inch) diameter, hollow, round, polypropylene bosses, the average break strength was 117 pounds per stake. In every case, the boss failed at the base, not at the stake. This type of failure mode indicates that the strength of the joint is limited not by the formed stake, but by the tensile strength of the cross section of the plastic boss.

Conclusions

Several heat staking methods for joining plastic parts together have been around for a long time. Each one has unique advantages and disadvantages. Through the use of infrared light as the energy source and the ability to control the environment around the plastic boss, the InfraStake process is an effective alternative to the conventional staking technologies.

References

1. M. Lanser, R. Miller, A. Van Klompenberg, U.S. Patent 6,544,022 (2003).

Key Words: Heat staking, infrared staking, plastic staking, InfraStake, plastic joining