

# **Advances in the Emabond™ Induction Welding Process for High-Performance Assembly of Demanding Thermoplastics**

**Russell J. Nichols, PE**  
Ashland Specialty Chemical Co.

## ***Abstract***

Electromagnetic (or induction) welding of thermoplastics is a simple, rapid and reliable assembly technique that produces structural, hermetic or high-pressure seals for most thermoplastic materials. Fusion temperature at the abutting interface of the parts to be bonded is achieved by using a specially formulated thermoplastic resin to absorb energy provided by an RF induction field. The process is widely used for such difficult-to-join materials as polyolefins and nylons. In addition to homogeneous polymers, the process can bond filled and/or glass fiber reinforced polymers to themselves or to selected dissimilar thermoplastics. The presentation outlines the design and manufacturing considerations implemented to achieve reliable, robust performance and details the advances and use of this process in several representative high-performance assembly applications.

## ***Introduction***

Welding of thermoplastic components is achieved when sufficient energy is introduced at the interface of the parts for local melting and fusion to occur. Various energy sources can be employed (i.e., a part can be heated to its fusion temperature by conductive heat transfer, mechanical energy can be dissipated by rotation or oscillation, and, ultrasonic or IR/laser energy can be delivered to bond interfaces). The application of mechanical energy and/or conductive heating causes displacement of material at the heated surfaces due to deformation. This flow at the interface may lead to dimensional variation in the finished assemblies and/or flow of excess material to the surface of the joined parts.

Electromagnetic welding is an alternative joining method in which induction heating provides a means of precise delivery of energy to a designed joint in which an implant material selectively absorbs energy, melts and flows to fill the joint. Resulting joints combine high strength – sufficient for structural, hermetic or high-pressure seals – with dimensional stability and aesthetically pleasing appearance.

## ***Induction Heating Technology***

Electromagnetic (or induction) heating results when a conductive material is placed in a varying magnetic field. The heating results from both eddy currents and hysteresis losses, with the relative magnitude of the two depending upon the magnetic properties

of the material to which the field is applied. In conductive, non-magnetic materials, only eddy current heating is possible, while in conductive, magnetic materials, both eddy current and hysteresis heating occurs.

In this process, ferromagnetic materials (susceptors) are mixed into polymers (matrix materials) to form proprietary compounds. The resulting compounds are applied to joints in the form of precision extruded profiles such as strand or tape, or as molded gaskets. Because the susceptor materials are distributed in a non-conducting polymer matrix, the resulting compound exhibits low electrical conductivity. This limits eddy current circulation (and the resultant Joule heating) in the same manner that laminated cores break the path for eddy currents in electrical transformers. Therefore, the primary mode of heating with these compounds is hysteresis losses.

Hysteresis heating occurs when magnetic materials are subjected to rapidly alternating (high frequency) magnetic fields. Magnetic hysteresis can best be visualized by plotting field intensity ( $H$ ) versus magnetic induction ( $B$ ) as shown in Figure 1. The initial magnetization curve (i.e., the point at which the energy is first applied to the susceptor) starts at the origin ( $H_0B_0$ ) and continues until the field intensity reaches the maximum value ( $H_{max}$ ) in the upper right quadrant. Thereafter, at each cycle of the applied RF field, the susceptor responds by completing the full cycle described by the dotted line. The area bounded by the hysteresis curve is proportional to the energy converted into heat. High frequencies are required because the incremental temperature rise for each hysteresis cycle is very small.

### ***Induction Welding Process Principles and Equipment***

The welding process begins with placement of the lower half of the part in the press, followed by insertion of the susceptor material, and placement of the upper half of the part in the press. As illustrated in Figure 2, the parts are held in close alignment to the work coil that delivers the induction energy by suitable fixtures. During joining, low pressure is applied to the parts until the heating is sufficient for the susceptor compound to reach its melt temperature initiating flow, and then high pressure is briefly applied to assure that the final positioning of the parts is correct. After joining, the susceptor compound has filled the designed gap in the joint and fused the mating parts, resulting in a polymer-to-polymer permanent bond.

The induction welding system includes an RF generator, application geometry specific work coils, an assembly press and tooling, the associated controls [i.e., a programmable logic controller (PLC) and human-machine-interface (HMI) or equivalents], the components to be joined, and the susceptor material. The key process interaction is that between the work coils and the susceptor material. The work coil can be thought of as an RF antenna and the generator is an RF transmitter. The generator/work coil system has to be tuned to perform properly. Although RF energy has the ability to propagate through air, it is known that the intensity of the field follows an inverse square function, so uniform heating is best achieved by maintaining a uniform distance between

the work coil and the bondline. Very long bondlines are often a great challenge to other joining methods, but induction welding is ideally suited to such components. Work coils have been designed to weld very large parts or to weld multiple (coils for up to 20 individual welds performed simultaneously are in commercial use) smaller parts simultaneously. Much of the proprietary technology involved in this field involves the design of the work coils to assure uniform heating performance. The performance of the energy delivery system is meaningless except in the context of the effective heating of the susceptor compound in the joint.

Material science considerations are involved in all susceptor formulations, in both the choice of matrix polymers and ferromagnetic susceptors. The polymer matrix material must be compatible with the parts to be joined. In the case of dissimilar polymers, great care must be taken to select materials with the capability of bonding with both substrates. The ferromagnetic susceptor material must be characterized to assure appropriate heating rates and any other requisite performance properties to meet the specific application requirements. The selection of the susceptor material includes determining how to best deliver the susceptor to the joint. Susceptor materials are pre-formed into a variety of profiles such as strand, sheet or tape, as shown in Figure 3. They can also be molded into customized gaskets for a wide variety of joint geometries. It is also possible to incorporate the susceptor compound directly into one of the parts to be assembled by insert molding, two-color molding, or co-extrusion.

### ***Joint Design***

Joint design is a highly interactive process for the development of new applications. A typical design cycle includes initial material compatibility testing, concept layout and development using 3-D solid modeling, design verification using prototype parts in laboratory presses, and validation of the commercial process using production parts in the production fixtures. Some typical joint designs are shown in Figure 4. The most widely used joint design is the tongue and groove shear joint. This design is flexible and can incorporate a number of significant design benefits, including the following: (1) positioning features, (2) pre-bond engagement of the joint for ease of assembly, (3) a physical stop to assure the relative position of the joined parts, and (4) directed flow of the susceptor compound within the joint. Ultimate joint strength is a function of interfacial bond area. A strong advantage of tongue and groove shear joints is that they can provide a large interfacial bond area within a thin wall joint.

### ***Flushmate™ Case History***

The pressure vessel of the Flushmate™ system is assembled from two components injection molded from polypropylene reinforced with 30% long glass fiber. After commercial introduction of assemblies joined using vibration welding, a small percentage of assemblies were found to experience failure of the joint during service. Root cause analysis defined three potential contributory factors to the failures: (1)

development of a resin depleted area at the interface of the joint as a result of the vibration welding process, (2) interrupted energy input at those bondline sections at right angles to the inline motion of the oscillatory vibration, and (3) variation in flatness of the contact surfaces of the molded parts.

In a change initiated to increase long-term reliability, the parts were redesigned to incorporate an induction welded tongue and groove shear joint, as shown in Figure 5. The induction welding process yielded an improved overall cycle time (26 seconds vs. 27-33 seconds for vibration welding). Comparative tensile strength, burst strength, and fatigue tests all displayed improved performance for the induction welded assemblies.

*Coupon Specimen Tensile Strength (Pounds per linear inch)*

COUPON	FRONT	BACK	LEFT	RIGHT
1	527	568	306	297
2	476	441	309	293
3	500	445	290	313
4	560	496	354	312
5	628	551	377	421
Mean	538.2	500.2	327.2	327.2
Std. Dev.	59.15	58.62	36.62	53.18

No bondline failures were observed, in all cases, the vessel wall was the limiting factor.

*Vessel Assembly Tensile Testing*

	Vessel Assembly
1	3090
2	3380
3	3440
4	3290
5	3370
Mean	3314.0
Std. Dev.	136.12

Tensile testing of vessel assemblies yielded zero bondline failures in over three years of production. Ultimate tensile values greater than 2500 pounds have consistently been achieved, with the failure mode being fracture of the parent material, not failure of the bondline.

*Hydrostatic Burst Testing*

Destructive testing of the assembled vessels demonstrated that the induction welded assemblies burst at pressure levels at least ten percent greater than those for production vibration welded assemblies.

### *Fatigue Testing*

The fatigue cycle test consists of applying compressed air at 50 PSIG for five seconds, and then bringing the vessel to ambient pressure for five seconds. The standard test is based on 50,000 cycles, after which the vessel is subjected to hydrostatic burst testing. Actual tests have been run as high as one million cycles with no evidence of high cycle fatigue. There have been no fatigue test failures of induction welded vessels.

### *Accelerated Life Cycle Testing*

Test stand cycling with 80 PSIG water supply pressure applied has consistently demonstrated in excess of 50,000 flush cycles with no anomalies.

The customer concluded that *“Induction welding is not as sensitive to process variables as vibration welding”*. Significantly, this product is sold with a lifetime warranty!

### *Other application examples*

<b>Application</b>	<b>Material</b>	<b>Unique Feature</b>	<b>Unique Benefit</b>	<b>Fig.</b>
Reverse Osmosis Water Tank	30% GF Polypropylene	10” Diameter	Pressure tight to 450 psi, NSF rated, 3-pc joint construction includes TPE bladder	6
Composite Storm Door	Glass mat Polypropylene	232 inch bondline	Exceptionally large bondline, one minute weld cycle	7
Automobile Load Floor	40% glass mat polypropylene	Bondline 296 inches	Eight individual joints, automatically dispensed susceptor material, fast machine cycle	8
Steering Wheel Airbag Cover	Santoprene / Polypropylene bond	Bondline 11 inches	Dissimilar material joining, assembly captures sensitive electronics	9
Power Steering Fluid Reservoir	33% GF Nylon 6	Four separate joints	70 psi leak proof – helium, Japanese OEM accepted	10
Blood Oxygenator	Polycarbonate	Eight individual joints	100% reliable leak proof, pressure-tight	11

## **Concluding remarks**

Induction welding is a proven and effective technology for welding thermoplastics. Developed largely by direct experimental observation, new rigor is being brought to the scientific understanding of the process both in terms of system engineering and material science. New systems benefit from improved sensors and process control systems that facilitate application of statistical process control (SPC) methods. Exciting new developments in susceptor technology and substrate material capabilities are emerging. Economical and reliable bonds can be applied to a widening range of materials and objects. Strong growth is occurring in automotive applications using nylon materials.

## **Acknowledgements**

Special thanks are due to Mr. Chuck Pelto at Sloan Flushmate for the information regarding the Flushmate™ application.

## **References**

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## **Definitions**

*Eddy current loss* – the heating due to Joule energy loss (or  $I^2R$  loss) in a ferromagnetic material upon application of an alternation (electro) magnetic field.

*Ferromagnetic materials* – substances with the ability to possess large permanent magnetizations even in the absence of an applied field.

*Hysteresis loop* – the plot of magnetization ( $B$ ) versus applied magnetic field intensity ( $H$ ) of a ferromagnetic material through one complete cycle of magnetization and demagnetization.

*Hysteresis loss* – the energy loss (seen as a temperature rise) involved in magnetizing and demagnetizing a ferromagnetic material.

Susceptor – a material that interacts with electromagnetic radiation to generate heat.

Figures:

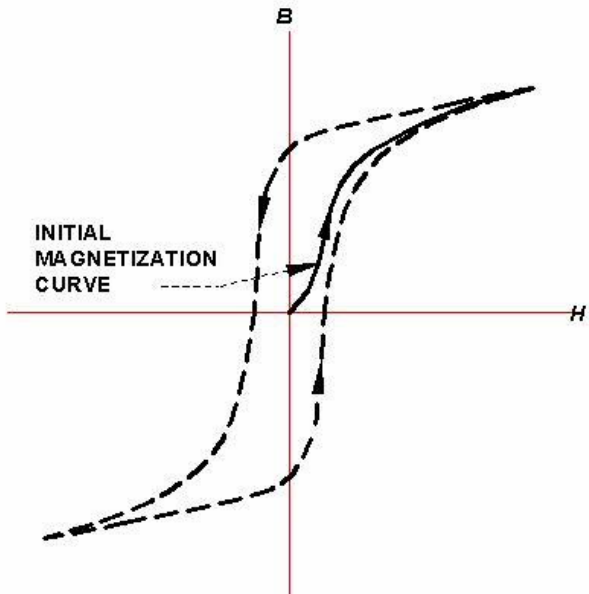


Figure 1 – Hysteresis loop

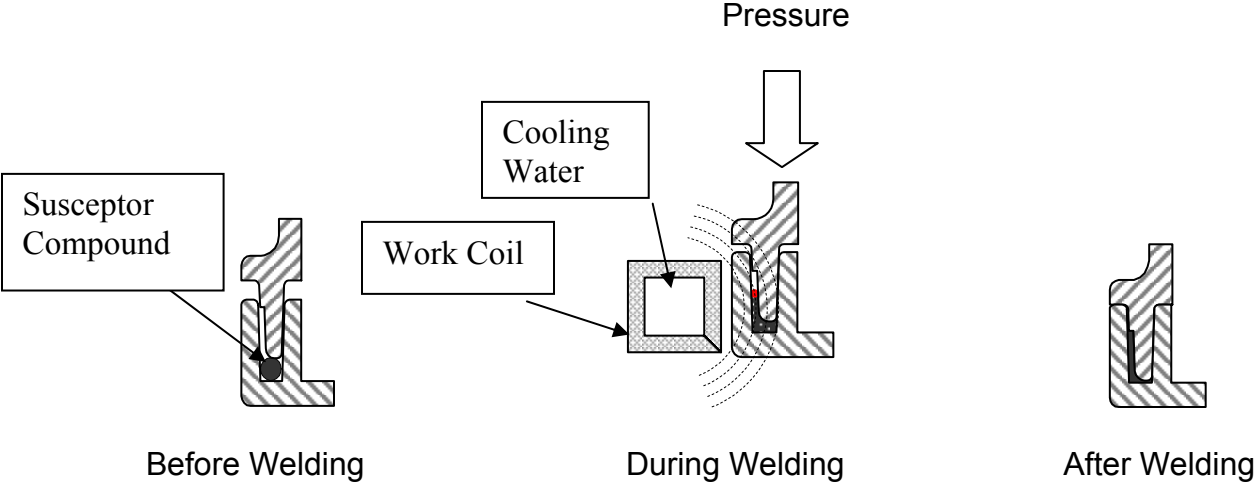


Figure 2 – Induction Welding Process



**Figure 3 – Susceptor Material Forms**



Flat to Flat – structural only



Flat to Groove – structural and limited leak-proof



Tongue in Groove – Most versatile, leak-proof, pressure tight



Step joint – For limited space, small, usually cylindrical, applications

**Figure 4 – Joint Design Alternatives**



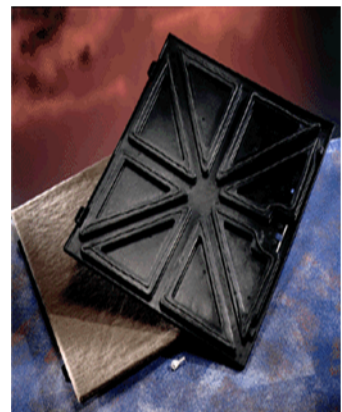
**Figure 5 - Induction Welded Flushmate™ Assembly**



**Figure 6  
RO Water Tank**



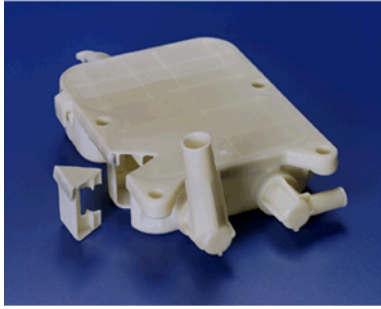
**Figure 7  
Composite Storm Door**



**Figure 8  
Automotive Load Floor**



**Figure 9**  
Steering Wheel  
Airbag Cover



**Figure 10**  
Power Steering  
Fluid Reservoir



**Figure 11**  
Blood Oxygenator