Joining Thermoplastics

Mr. V. Kumar
(Proprietor - Nevik Ultrasonic)

Over the past years, there have been an amazing number of applications where plastics have displaced traditional materials – in consumer goods and in engineering applications.

This has been made possible by the fast paced development and use of Plastics, for ever more challenging applications.

There is now this growing urge to produce more complex forms from plastics, and this, in turn, has multiplied the challenges of joining them, whether to similar materials or to dissimilar materials.

For example, engineers have dreamt and worked towards building an all-Plastic Automotive Engine for the past many years.

While this still remains work-in-progress, many under-the-bonnet components have been successfully replaced by Plastics.

Plastic intake air manifolds, filter housings and fluid reservoirs, all-plastic fuel storage and delivery systems, lighting, instrument panels, ducts, interior trim and upholstery, bumper systems, fenders, et al, are the norm now!

An interesting offshoot is the endeavour of automotive engineers to use recycled plastics for body panels. Already a prototype car with transparent body parts has been built – e.g. a full canopy transparent roof, from the windshield to the rear panel, along with transparent side doors.

Pic 1:

The Chevrolet Volt, uses Lexan in its roof and side windows, while the doors and hood are made from other plastic composites.

Pic 2:

The Hyundai Qarmaq uses transparent doors for style, but its plastic hood is designed to be pliable enough to decrease harm to pedestrians in an accident.

Work now continues to include other systems, combining injection and blow moulded parts, as well as soft elastomers and hard plastics, to gain unique properties in individual functions, and to minimize production times and costs.

The motivations driving the increased use of plastics in almost all applications are:

1. Environmental concerns, with possible use of recycled plastics.
2. Freedom of Design to Industrial Designers – Plastics are easier to form and finish.
3. Economic concerns - Lower material cost.
4. Lower Tooling Costs to manufacture components.
5. Lower Weight – Better efficiencies Joining Plastics is a tricky business.

It is dependent, amongst a host of issues, on :

1. Nature of the Polymer (Thermoplastic/Thermoset, Amorphous / Semi - Crystalline)
2. Weld specifications – Mechanical strength, Pressure-tight seals, Aesthetics, Function
3. Geometry of the components
4. Weld Area
5. Accessibility to the Weld Area
6. Ability to provide support under the weld area by good fixturing, and, of course
7. Volumes to be welded

Traditional assembly methods - Screws and Mechanical Fasteners, Press & Snap fits, Chemicals, Solvents & Adhesives are generally unlikely to cope with the challenges.

Joining Thermoplastics

Methods such as Impulse Welding, Hot Plate, Hot Air/Gas, Extrusion, Electro-Magnetic Induction, Resistive & Induction Implants, Spin Welding, RF Welders etc have been around for many, many years, and their applications as well as limitations are well understood.

Amongst the newer processes, Ultrasonics, Vibration, Infrared & Lasers could perhaps cope with the new challenges – joining exotic grades of plastics, in mega-volume quantities, with minimal rejects. These are discussed in some detail in this article.

It needs to be understood that each process demands a very specific design, especially at the weld interface, to achieve desired results.

It is therefore imperative to first select the joining (or welding) process to be used, and then design the parts to be welded, in accordance with the design required by the specific process.

Almost all plastic welding processes are based on application of Heat at the weld interface.

Innovative methods have been designed to do this, and all such methods can be categorized into three distinct groups:

- **External Heat Source** – Impulse Welding, Hot Plate, Hot Air / Gas, Extrusion
- **Mechanical Movement** – Spin Welding, Ultrasonic Welding, and Linear or Orbital Vibration Welding
- **From Electromagnetism** – Resistive Implants, Induction, High Frequency (Dielectric), Infrared & Lasers

Common concerns with **External Heat:**

1. The process calls for clean surfaces, because contaminated surfaces will not bond well.
2. It is not very energy efficient, because the heated tool has to be maintained at a predetermined temperature throughout the work shift, even when used intermittently.
3. This process is influenced by ambient conditions, because ambient temperature variations affect the temperature of the heated tool, as well as its designed heat dissipation characteristics.

After External Heat Sources, Friction techniques based on Mechanical Movements, to generate internal heat at the interface itself, gained popularity.

The breakthrough for ultrasonic welding of plastics came when a single ultrasonic transducer was developed to transmit hundreds or thousands of watts ultrasonic energy through one Piezoelectric element. Thus was born Ultrasonic Welding (Assembly) of Thermoplastics.

Ultrasonic Welding bloomed into a process of choice, with its ability to weld almost every thermoplastic, within milliseconds, eliminating consumables, and without the need to pre-clean the components, or the necessity to cure them thereafter.

The process is based on creating frictional heat between two plastic components, by vibrating them relative to each other, at Ultrasonic Frequencies (15 to 40 Khz). The maximum amplitude of vibration is the order of 100 - 150 microns peak to peak.

Pic 3: Typical Bench Top Ultrasonic Welder – courtesy Bransons USA.

One component is held rigidly in a fixture, the other contacts a Sonotrode (an electrode that transmits sound energy, sometimes called a Horn, because a "Horn" emits Sound).

When the Sonotrode is excited, it creates inter-molecular and intra-molecular friction in the plastic components, and generates heat, very locally and very rapidly, only at the interface, which melts the plastic faces and welds the two components together, as soon as the ultrasonic vibration is stopped and the plastic resolidifies under applied pressure.

The system is incredibly fast. Most welds take under one second - yes, one second - ultrasonic exposure. The process uses no consumables of any nature, calls for no pre-cleaning, or post curing, is energy efficient, and gives consistent, repeatable results. It is a "hungry" process, and ideally suited for mega-volume applications, due to its speed and consistency.

Semi- or complete automation increases productivity, process control is in-built, and it is common to find e.g. medical device manufacturers using this production technique extensively to produce life saving gadgets, in large numbers, with the greatest reliability and quality.

Innumerable processes evolved from the basic ultrasonic welding process:

- Ultrasonic Staking (or riveting parts together) reforming plastic "rivets" or studs, premoulded on the components, with matching holes,
- Ultrasonic Insertion - inserting tapped metal bushes into plastic parts, post moulding

- Ultrasonic Swaging - reforming plastic projections to capture and lock another component, invariably of dis-similar material,
- Ultrasonic Spot Welding Plastic Sheet materials together
- Ultrasonic Sealing Films and Fabrics (even cutting the sealed edges simultaneously)
- Ultrasonic Punching non-circular profiles, Ultrasonic Cutting Rubber sheets/mouldings, even Ultrasonic Cutting Cakes, Pastries, Chocolates, with effortless ease, quickly and cleanly.

Pic 4: Ultrasonic Cut & Seal applications – courtesy Sonobond Ultrasonics, USA.

The scope of the process genuinely seems limited by one's imagination.

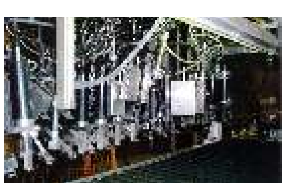
Systems have since been built to measure the energy consumed for each weld, and sound alarms or activate devices, if energy levels do not fall within predetermined tolerances. Such systems also control the "depth" of weld, in height critical applications. This enables an incredible level of quality control, in-built into the process.

However, even as its popularity grew, and Ultrasonics became the first choice for welding mega-volume plastic parts, constraints of the technology began to surface. For example, it could not cope with large parts, or semi crystalline materials that demanded a hermetic seal.

Amongst the most serious limitations that emerged was its inability to weld lengths in excess of ~ 10 to 15 inches. Reason : A single Horn, with uniform ultrasonic activity on its working face, was very difficult to build beyond such dimensions.

An option that emerged was to use multiple systems in a "Gang" format, to cover weld lengths or geometries in excess of this dimension. Numerous systems were thus "ganged" together, and synchronized or programmed to cover larger weld areas.

Pic 5: 70 systems "Ganged" together to weld vehicle defroster nozzles to vehicle dashboard – courtesy Steckmann Ultrasonics, Germany.



The current set of machines popularly used for manufacture of Non-Woven Multi-Layer King sized Quilts, or Large-sized Non-Woven Shopping Bags, use similar configurations.

Pic 6: Quilt machine courtesy - King Ultrasonics, Taiwan.

The "Gang" concept, however, multiplied the initial investment in equipment several times over, so investments were reduced by adding a Programmable Logic Controller to supply Ultrasonics from a limited number of Ultrasonic Generators to a large number of transducers, in a pre-determined manner.

An interesting innovation used servo controlled X-Y tables to locate and move large parts at desired welding points while the horn remained stationary, or move the Ultrasonic Stack each time to a desired welding point, keeping the part stationary.

The X-Y table was soon replaced by a Robot, so the system became even more versatile, and could deal with variations in the Z axis too! The Robot was able to make small welds at multiple points on large parts.

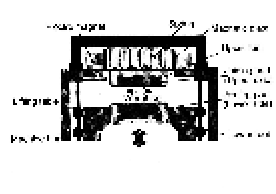
This configuration presents one of the most versatile Ultrasonic systems that can make welds in 3D Parts, within a large radius, limited only by the reach of the robot arm.

Pic 7: Robot with Ultrasonic Horn – courtesy Steckmann Ultrasonics, Germany.

Nevertheless, where large parts, especially semi-crystalline plastics need to be welded along their entire perimeter, to provide leak-tight seals, as in air filter or fuel filter housings, Ultrasonics was found wanting.

This led to the development of Linear Vibration (Friction) Welding system, which could accommodate parts as large as an automotive bumper. Such welders simply generate linear friction by moving one part over the other in a linear motion – at low frequency, say 100 Hz or 200 Hz, One component is placed in a rigid nest, mounted on a lifting table, while the second component is placed in a nest attached to an electro-magnet, held in neutral position by flat springs.

Pic 8: Schematic of Linear Vibration Welder – courtesy Plastics Pocket Power, USA.



Once the parts are loaded into their respective nests, a hydraulic or pneumatic "lift" brings the lower component into contact with the upper one, clamps the two components under pressure, and activates the electromagnet to create a reciprocating movement – against the springs – at an amplitude 1 to 2 mm peak to peak.

This creates friction, heat, and melts at the interface.

Once the reciprocating movement stops, the springs snap the parts back into their original position, the plastic resolidifies, and the parts are welded in perfect alignment. This is especially beneficial when welding components with partitions, because at the end of the weld cycle, each partition too is welded in perfect alignment.

In this process it is essential to design parts with freedom of motion in a linear direction.

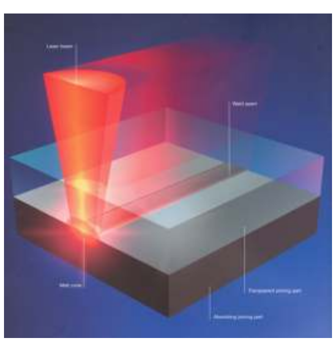
The limitations of Linear Motion Welders for non linear weld configurations led to the development of Orbital Motion Vibration Welders, to achieve better welds. Here the linear movement is replaced by an orbital movement, because this is more appropriate for circular or non-linear weld configurations.

Infrared rays penetrate to useful depths by radiation, so it is possible to transmit heat - without contact – through the upper surface and into the part interface. This eliminates marking and/or contamination on the part surfaces, and is in fact faster than the direct contact Hot Plate Welding process. Sources of infrared radiation include Lasers, Quartz lamps and Ceramic Heaters. Each source has a specific wavelength, and can be selected per application needs.

Lasers are very versatile and offer a focused beam of intense radiation, in the infrared range of Electromagnetic spectrum, to heat and melt plastic at the interface. Low & Medium Power near infrared Diode Laser is popularly used to Laser-weld Plastics.

The principle is known as transmission welding, where precise controllable heating is produced at the interface between a laser-transmissive and laser-absorptive plastic. The laser beam penetrates the transparent plastic, and is converted to heat in the absorbing plastic. At the interface, this heat causes material melt, and bonding.

Pic 9: Laser Welding Principle – courtesy Leister, Switzerland.



Surprisingly, it is the colour of the plastic that determines whether it will transmit or absorb laser energy! All polymers are more or less transparent (in undoped condition) in the infrared wavelength of laser sources (except CO_2 lasers). Filler materials, usually pigments, provide for absorption of laser energy. Most common is the use of carbon black particles acting as absorbers, typically in a concentration of 0.05 – 0.5%. However this results in darker colours.

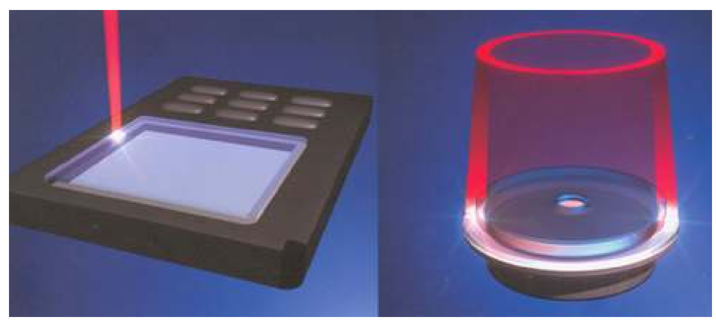
For clear and bright colours, other pigments – more flexible to use – have been developed. Sometimes, application of special dyes at the interface helps achieve the same results. But the use of a consumable, and the wherewithal to apply it precisely, on mega-volumes, inhibits the use of difficult-to-weld colours

The Laser beam source may transmit the laser beam through optical media for direct application, or through optic fibre coupled systems.

Different concepts are used to make the laser cover the weld perimeter – such as contour or line welding, simultaneous and quasi simultaneous welding, as well as mask welding.

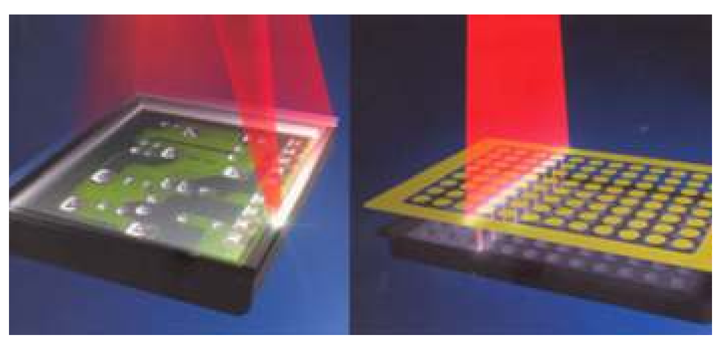
In contour or line welding, a laser spot is guided along a weld profile in a single pass; in simultaneous welding, the laser hits the entire weld profile simultaneously. In quasi-simultaneous welding, the laser spot makes multiple high speed passes over the weld profile.

Pic 10: Laser Welding Concepts – courtesy Leister, Switzerland.



In mask welding, a curtain laser beam scans the entire part, with a mask between the part and the laser, that permits the laser to pass at specific areas only.

Pic 11: Laser Welding Concepts – courtesy Leister, Switzerland.



Laser welding is a fast, clean, non-contact process that keeps flash and distortion to an absolute minimum. It offers flexibility, high efficiency and the ability to integrate into manufacturing facilities. There is virtually no chance this process will impair delicate parts inside an assembly during the welding

Pic 12: Laser Welding Equipment - courtesy Laserline Gmbh.

What's next in Joining Plastics ?

There is no doubt all methods used to join plastics eventually end up depending on their ability to heat the interface. So enterprising researchers wondered if they could use a Free Source of Heat for this purpose – Solar Energy.

Is this a serious option ?

Experimental work was done in Australia some years back.

A Solar Energy Concentrator[6] (SEC), employing primary and secondary mirrors, focused sunlight on a lens for delivery and further concentration onto a specimen surface. The experimental setup used a reflectivity in the wavelength range 400 - 1200 nm, and placed ABS, PC and PMMA components on specially prepared specimen holders.

Pic 13 : SEC System used for experimental plastic welding.

Briefly, they found they could weld these specimens – the opaque ones (ABS) welded better than the transparent ones (PC & PMMA), probably because the former absorbed most of the solar radiation, while the latter transmitted or reflected most of the solar radiation.

They achieved average weld strengths (of parent material strength) ranging from 38% for ABS, 25% for PC, and 34% for PMMA.

ABS had the fastest response, although it has higher glass transition temperature than PMMA.

The transparent plastics transmitted most of the energy, absorbed very little, and reflected some – this resulted in melt only at the surface while the bottom layer remained in its glass transition stage.

Longer welding times were required for transparent materials than for opaque materials, as the opaque materials absorbed more energy.

Compressive forces were constantly applied during the welding cycle, and this resulted in some air being trapped inside the PC weld ; in PMMA, air bubbles actually emerged from the bottom layer and natural convection lifted them to the surface.

Clearly a lot more work needs to be done to use this abundantly available resource, and perhaps new avenues will open up.

Meantime, Plastics continue displacing traditional materials – at an amazing rate - and Engineers and Technologists have a challenge on their hands. The challenge lies not just in disposing used plastics products in an environment-friendly manner, but of joining the innumerable plastic components that need to be integrated into newer products each day.

References :

1. http://reviews.cnet.com/4520-13529_7-6740435-1.html - CNET Review
2. understanding Ultrasonic Plastics Assembly – V Kumar
3. http://www4.hcmut.edu.vn/~dantn/TWI/jk55.html
4. Plastics Pocket Power – Prof T A Osswald, USA
5. http://www.medicalsearch.com.au/Products/Diode-Lasers-For-Durable-Joining-Of-Thermoplastic-Polymers-53088
6. Joining of Thermoplastics Using a Cassegrainian Solar Energy Concentrator Stoynov, Lubomir A., Yarlagadda, Prasad K., & Wong, Walter C. (2000)
7. Commercial Literature(s) of numerous Plastic Joining Equipment Manufacturers' in Europe, USA, Far East and India (including Bielomatik Gmbh, Branson USA, King Taiwan, KWH Gmbh, Laserline Gmbh, Leister Switzerland, Markperi USA, Pfaff Gmbh, TWI-UK, Sonobond USA, Steckmann Gmbh)

About the Author :

V. Kumar is a Mechanical Engineer, with vast experience in marketing, servicing and maintaining Capital Goods. He has been actively involved in Plastics Assembly for over 30 years – primarily in Ultrasonic Plastics Assembly.

During this period, he has assisted numerous users switch from subjective, labour intensive joining methods to semi-automated, consistent and reliable methods.

His close interactions with users, and leading companies worldwide, has given him an overall perspective in Plastic Assembly methods, and he is happy to share his hands-on experiences to find innovative solutions.

His business venture – nevik ultrasonics – focuses on Design, Manufacture and Supply of Ultrasonic Horns & Fixtures, and offers Technical Services, such as Selection of Optimum Process for Plastic Welding, Sourcing Equipments, Troubleshooting Applications, Training Personnel in Design, Operation, Production & Maintenance of Ultrasonic Equipments & Systems, etc.