

Vibration welding

Executive summary

An understanding of the vibration welding process and how its process parameters affect weld strength has begun to evolve in the last decade, but the information is scattered over many papers in the technical literature. The main purpose of this manual is to provide design engineers with a state-of-the-art knowledge base to enable them to design plastic joints. However, this manual does not discuss details and setup procedures for particular machines, and is not intended as a shop-floor manual.

The reasons that joining of plastics is becoming important and the different types of joining methods are first briefly discussed. The vibration welding method, its advantages and shortcomings, and typical applications are then described. This is followed by sections that provide detailed descriptions of the vibration welding process phenomenology, the effects of the process parameters on the weld strengths of many unfilled and filled thermoplastics - including welds of dissimilar materials - and their blends, joint design and machine considerations. A guide to the literature on vibration welding of plastics is provided for detailed information on the welding of particular resins.

Design rules

Overview

In vibration welding also called linear welding and linear friction welding - the surfaces to be joined are rubbed against each other, under pressure. The resulting frictional work causes the interfacial material to heat up and melt. Welding is then completed by allowing the molten film to cool under pressure.

The main process parameters are

- the weld frequency, n
- the amplitude of the vibratory motion, a
- the weld pressure, P_0

The vibration welding process is ideally suited to the welding of thermoplastic parts along flat seams. The process can also accommodate seams with small out-of-plane curvature.

The relative strength, or weld factor, is one measure of weld strength. Relative strength is the strength of the weld divided by the strength of the virgin material in the same test.

Under the right conditions, very high weld strengths and ductilities - equal to those of the virgin resin - can be achieved in thermoplastic welds made by the vibration welding process.

Phases

Polymer weld processes can be divided into the four phases: solid friction, transient flow, steady-state flow and solidification.

- Penetration-time curves measure the area of weld penetration in relation to vibrational frequency, pressure and time. Penetration-time curves are important because they determine the penetration level at which a steady state is attained.
- High weld strengths and ductilities in thermoplastic welds have been demonstrated over a frequency range of 25 to 400 Hz, a weld pressure of 0.34 MPa (49 psi) to 20.7 MPa (3000 psi), and a range of weld amplitudes from 0.32 mm (0.0125 in) to 1.59 mm (0.0625 in). However, the optimum weld parameters are different for each thermoplastic.
- Tests have shown that, for a large range of amplitudes, frequencies and pressures, the weld strengths of nominally 6.35 mm (0.25 in) thick specimens are not very sensitive to the weld process parameters as long as the penetration, η_r , is greater than a threshold value, $\eta_{r,c}$, of about 0.25 mm (0.01 in).
- Resins with fillers, and resins that are blends, also show this four-phase behavior.

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Phenomenology

The phenomenology of vibration welding is best described by weld penetration. Weld penetration is the most important parameter affecting weld strength.

- During welding the externally imposed weld pressure causes the molten interfacial film to flow laterally outwards, thereby resulting in the two parts coming closer.
- The decrease in the distance between two parts, caused by this lateral outflow, is called weld penetration.

The next most important parameter is the weld pressure, P_w , which affects each polymer differently.

Weld frequency appears to have a large effect only on polyetherimide, of the many resins discussed in this guide. Weld strengths corresponding to those of the virgin polyetherimide resin can be achieved only at high weld frequencies.

Weld amplitude by itself does not affect the welding process; the energy input into the process is determined by the product of the amplitude and the frequency. However, weld amplitude is important in cross-thickness welding, in which the vibratory motion is normal to the thickness direction.

Overall cycle time increases with increasing part thickness.

- The penetration at which steady-state conditions are attained (and hence the threshold penetration) increases with specimen thickness but decreases with increasing weld pressure.
- Low weld pressures not only result in increased cycle times, but can also result in unacceptably high threshold penetrations.
- If penetration-based controls are used for terminating the weld cycle, then the threshold penetration must be adjusted to account for both the pressure and the part thickness.

In many applications, such as in the welding of closed seams of box-like or tubular parts, the linear vibratory motion used for generating frictional heat occurs along the part-thickness direction. In such cases a portion of the molten layer along the entire seam is exposed to the ambient air during each vibratory cycle; the resulting temperature reduction can affect weld quality.

Dissimilar materials and other resin material types

Although welds between dissimilar materials exhibit the four phases of welding observed in neat resins, high weld strength is not necessarily achieved once an apparent steady state has been attained.

- Apparent steady-state conditions indicated by penetration-time curves are deceptive because of differences in “melt” temperatures and viscosities. One resin with high melting and flow rates may mask the still-developing melt and flow conditions in the dissimilar resin at the point when an apparent steady state has been attained.
- In this case, weld strength continues to increase even when penetration falls in the steady-state regime. Because of this effect, additional information is required for optimizing welds between dissimilar materials.

High strengths can be achieved in structural foam welds.

Measurement of weld strength

Measurement of weld strength requires more than static strength obtained by a tensile test.

- Creep rupture may be more important than static strength in some applications
- Impact resistance may be important in other applications
- Fatigue considerations, in general, have an inadequately small amount of available data
- Residual stresses caused by the generally rapid cooling of the weld zone have not been characterized

For optimum process conditions, refer directly to the Processing section.

Design guidelines

There are four elements of joint design: design for joining (welding), design for strength, aesthetic considerations and fixture design.

- Because joining has not been considered important in the past, when welding is required it tends to be considered after the part has been designed and the process chosen.
- Clearly, assembly considerations and joint design must form an integral part of the part design process.
- The choice of the welding method depends on the part geometry, size and functional requirements of the joint.

In thin-walled parts, most joints are formed at near-rectangular intersections, resulting in T or L joints.

- A good practice is to provide a small flange on one of the mating sections.
- In very thin “T” or “L” joints there is a possibility of weld “read through” caused by differential shrinkage at the weld interface. The problem can be avoided by a local thickening of the appearance surface.
- When weld flash presents an esthetic issue, the preferred solution is to mold in “flash traps.” These are small cavities in one or both mating surfaces at the joint interface into which the laterally extruding melt, that normally forms the flash, would flow.

All welding methods require fixturing that is part and welding-technique specific.

- The fixturing must hold the parts such that the desired motion can be generated at the interface at the desired weld amplitude and pressure.
- This normally requires that each of the parts be effectively clamped as close to the interface as possible.
- Furthermore, the fixtures must be so designed that the desired weld pressure can be generated along the entire seam.

Commercial vibration-welding machines

In commercial vibration welding machines, the moving half of the parts to be welded are vibrated by exciting a tuned, stiff-spring and mass system by means of an externally imposed oscillatory force. The main limitation of commercial machines is that they do not have penetration control.

A weld may not perform well for many reasons

- Poor weldability of the material - check data on weldability
- Weld process parameters chosen incorrectly - check recommended process parameters
- Poor joint design - placed in highly stressed region or flexes in an undesirable way during welding, resulting in a poor weld
- Poorly designed fixturing, resulting in a nonuniform weld pressure and in an inadequate weld amplitude due to part flexing - carefully analyze the structural design of the fixture.

Importance of joining

Until recently, joining of plastics did not receive much attention. Plastic parts, most of them non-structural, could be molded in sufficient complexity to avoid the need for assembly. Important exceptions were high-performance composites made of thermoset-resin-based unidirectional laminates, mainly used by the aerospace industry, for which adhesive bonding and mechanical fastening technologies were developed.

Now the joining of plastics and plastic composites is becoming important for several reasons. First, such materials are increasingly being used in complex structural assemblies, in which joining considerations and cost are becoming important. Second, the emerging structural (load-bearing) applications of plastics require structural joints that must withstand static and fatigue loads. Third, weldable filled and unfilled thermoplastics resins are being used in many demanding structural applications. A good example is the first all-plastic 8-km/h (5-mph) automotive bumper, made of an unfilled thermoplastic blend (Xenoy* 1102 resin) specially developed for this application, which was fabricated by vibration welding two injection-molded parts. Welding is also becoming important because of the advent of high-performance thermoplastic composites, the use of which may revolutionize assembly techniques in aerospace applications. More recently, recyclability considerations have made welding an even more attractive assembly technique because, in contrast to the use of adhesives, additional materials are not introduced into the assembly.

The efficient use of plastics and plastic composites requires that different parts of a structure be made of materials which may include metals and fabrics that optimize part performance and cost. For example, thin-walled, blow-molded structural parts can be stiffened by filling the cavity with low-density foam. Future automobile doors may satisfy design requirements using several different plastics and composites in combination with metals and fabrics. Such innovative ways of using plastics will require new insights and technologies for multimaterial part design, fabrication and assembly. This need is driving the development of a new generation of multiprocessing machines that can execute two or more plastics processes simultaneously or serially, in the same mold, to fabricate multimaterial parts. Such emerging technologies place increasing demands on joining methods for attaching or bonding different types of plastics to plastics or to other materials. The emerging need for efficient joining methods is bound to result in the invention of new joining technologies.

Some issues

Joint design depends on the materials being used, on the required performance, and on the joining technology used; joint performance will depend on the characteristics of the process used. Important considerations for joint quality in structural applications are

- How strong is the joint under static loads?
- How resistant is it to impact loads?
- What is the effect of residual stresses?
- How does the joint perform under fatigue loading?
- How does creep of the resin(s) affect long-term joint performance?
- What effect does resin aging have on joint performance?
- What is the effect of fillers such as particulates and fibers?
- How do environmental factors influence joint performance?

Unfortunately, except for some aspects of mechanical fastening and adhesive bonding, current joining technology for plastics is not based on an understanding of the underlying fundamental processes. Certainly, the welding processes are not well understood, both from the standpoint of process mechanics and in the sense that the effects of process parameters on joint performance have not been adequately quantified. An overview of the state-of-the-art on joining methods for plastics and plastic composites is available in Reference 1.

The purpose of this manual is to provide a comprehensive knowledge base for the vibration welding of plastics, a process that has been characterized over the last decade, but for which the information is scattered over many publications. This manual is intended for the design engineer.

Classification of joining methods

Joining of plastic materials and their composites can broadly be divided into mechanical fastening and bonding (figure 1). Bonding can further be classified into adhesive bonding, solvent bonding and welding. Mechanical fastening and adhesive bonding can be used for joining all materials, including metals. And the parts to be joined need not be of the same material. On the other hand, welding of plastics, which requires the materials at the joint interface to melt, is only applicable to thermoplastics. (Thermosets, in which a chemical cross-linking reaction occurs during part processing, cannot be welded; a molded part does not soften upon reheating and the shape can only be changed by machining.) Depending on how the heat for melting is supplied, welding can broadly be classified as

thermal bonding, comprising

- hot gas welding
- extrusion welding
- hot-tool (hot-plate) welding
- infrared heating

friction (mechanical) welding, incorporating

- spin welding
- angular vibration welding
- orbital welding
- vibration welding
- ultrasonic welding

electromagnetic bonding, which includes

- resistance (implant) welding
- induction welding
- dielectric heating
- microwave heating (figure 2)

Figure 1
Classification of joining methods

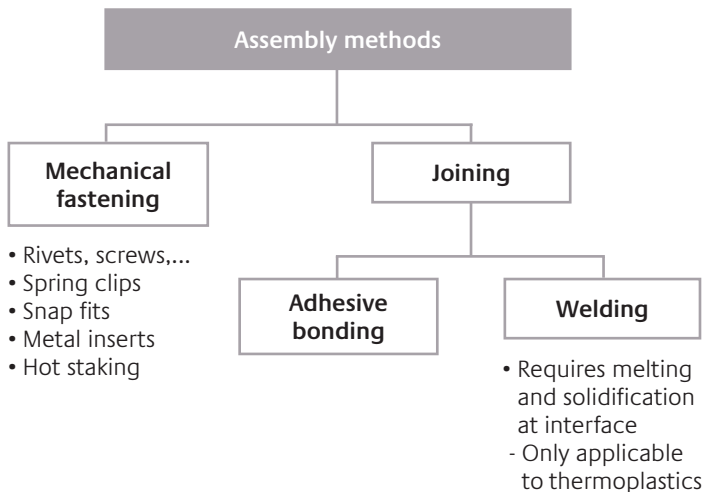
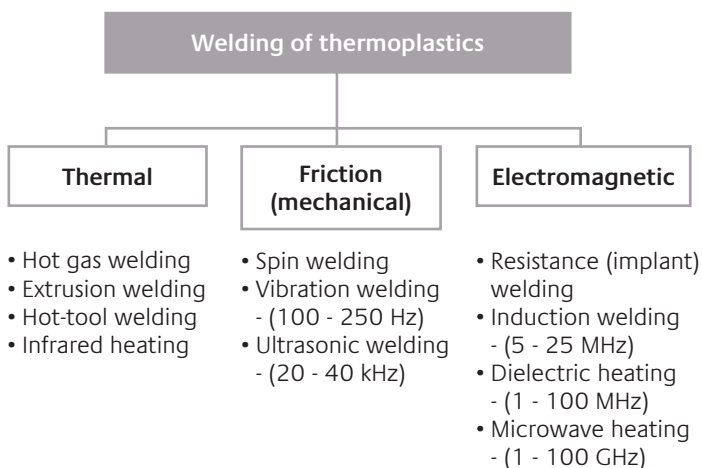


Figure 2
Classification of welding methods for thermoplastics



Vibration welding

The process

In vibration welding, also called linear welding and linear friction welding, the surfaces to be joined are rubbed against each other, under pressure, in an oscillatory manner, as schematically shown in figure 3. The resulting frictional work causes the interfacial material to heat up and melt. Welding is then completed by allowing the molten film to cool under pressure. The main process parameters are

- Weld frequency, n
- Amplitude of the vibratory motion, a
- Weld pressure
- Weld time

Most industrial machines operate at fixed weld frequencies of 120 Hz and 240 Hz (100 and 200 Hz where the electricity line frequency is 50 Hz, such as in the UK), although higher frequency machines are also available. The amplitude of vibration is normally less than 5 mm (0.2 in), and the weld time varies from 1 to 10 seconds. The vibratory motion is normally produced by exciting a tuned spring-mass system. At higher frequencies (>240 Hz) welds can be achieved at amplitudes as low as 0.32 mm (0.013 in). This can be important in applications in which a part has to be welded into a recessed cavity, wherein the clearances may not be sufficient for large-amplitude vibration.

Advantages and shortcomings

The vibration welding process is ideally suited for welding of thermoplastic parts along flat seams. The process can also accommodate seams with small out-of-plane curvature. This technique has many potential advantages for joining large flat-seamed thermoplastic parts: (1) relatively short cycle times, (2) simple equipment and (3) insensitivity of the process to weld surface preparation. In contrast to adhesive bonding, no foreign material is introduced, so that the weld interface is of the same material as the parts to be welded. Also, in contrast to hot-tool welding, in which the interfaces to be welded are heated conductively by direct contact with a hot tool, the heating is very localized. Moreover, the vibration welding process is far more controllable and is much less likely to cause material degradation because of overheating at the interface.

The main disadvantage of this process is that it is limited to nearly flat-seamed parts, although stepped parallel seams can also be welded. Also, this process is not suited to welding low-modulus thermoplastics, such as some thermoplastic elastomers.

Typical applications

To date, the most demanding application of vibration welding - from the standpoints of large part weld size and required weld strength - has been the first all-plastic automotive bumper. This part was molded from Xenoy* 1102 resin, an unfilled blend of polycarbonate (PC) and polybutylene terephthalate (PBT), and was designed to withstand an 8-km/h (5 mph) impact. Other applications of this technology in the automotive industry include the welding of headlight, taillight and instrument-panel assemblies - these applications involve welding polycarbonate to itself and to acrylic-acetal gasoline reservoirs, 30% glass-filled nylon brake-fluid reservoirs, and polypropylene compartment-access doors welded in 2 planes. In the appliance industry, this technology has been used for assembling glass- and particulate-filled polypropylene washer and dishwasher pumps, and particulate-filled soap dispensers and dishwasher spray arms. It has also been used for welding chain-saw motor housings made of 30% glass-filled nylon.

The vibration welding process

Process phenomenology

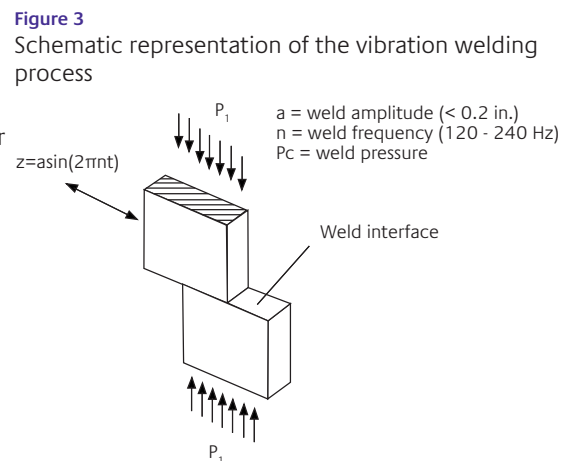
The process phenomenology of vibration welding has been characterized experimentally in References 7 and 8, and process models are available in References 9 and 10.

For a detailed discussion of vibration welding process phenomenology, see Appendix A-2.

Effects of process parameters on weld strength

Under the right conditions, very high weld strengths and ductilities - equal to those of the virgin resin - can be achieved in thermoplastic welds made by the vibration welding process. High weld strengths and ductilities in thermoplastics have been demonstrated over a frequency range of 25 to 400 Hz, a weld pressure of 0.34 MPa (49 psi) to 20.7 MPa (3 ksi), and a range of weld amplitudes from 0.32 mm (0.0125 in) to 1.59 mm (0.0625 in). However, the optimum weld parameters are different for each thermoplastic.

The effects of weld process conditions on weld strength of the four resins considered in Section 3.1 are discussed in detail in References 11 and 12.



Threshold penetration

Of the many weld parameters, namely the amplitude, a , the frequency, n , the pressure P_0 , the penetration η_r , and the weld time, t_0 , the parameter having the largest effect on weld strength is the penetration. Tests have shown that, for a large range of amplitudes, frequencies and pressures, the weld strengths of nominally 6.35 mm (0.25 in) thick specimens are not very sensitive to the weld process parameters as long as the penetration, η_r , is greater than a threshold value, η_r , of about 0.25 mm (0.01 in). For penetration below this threshold, weld strength appears to fall off and become unpredictable, while predictable and relatively constant strengths can be achieved for penetration above this threshold. In fact, the penetration appears to be the single most important factor affecting weld strength. Weld time by itself is not a good indicator of weld quality, and should not therefore be used as a weld machine control parameter. However, the penetration is not the only variable affecting strength. Also, the penetration threshold may be a function of the weld-specimen thickness.

A comparison of penetration-time curve data with weld-strength data has shown that the penetration threshold corresponds to a penetration in the steady-state regime of melting and flow. Tests have also shown that continued welding into the steady-state regime does not affect quality. Thus, the penetration threshold for any specimen thickness is the penetration at which a steady state is attained. This threshold can be obtained by generating a time-penetration curve under conditions of specified frequency, amplitude and pressure.

At first glance it would seem that the threshold penetration η_r should correspond to a unique time that could be used as a weld control parameter. However, the times t_1 and t_2 (figure 4) for regimes I and II, respectively, depend on the initial surface preparation and alignment, so that there can be a considerable variation in time $t_1 + t_2$ required for attaining the penetration η_r . Therefore, penetration control is recommended for achieving the best welds. For machines not offering penetration control, the weld time should be increased to account for the expected variations in t_1 and t_2 .

Effect of pressure

The next important parameter is the weld pressure, P_0 , which affects each polymer differently. Both the weld strength and the ductility of unfilled Lexan* polycarbonate resin are relatively insensitive to the pressure P_0 in the range of 0.9 (130) to 6.9 MPa (1 ksi), but fall off at pressures of about 13.8 MPa (2000 ksi).

A similar trend is exhibited by the data for unfilled Valox* PBT resin. In contrast to unfilled Lexan polycarbonate resin, and unfilled Valox PBT resin, welds of unfilled FR Noryl* PPO/PS resin attain the highest strengths at the lowest pressures. On the other hand, the strengths of welds of unfilled Ultem* PEI resin increase systematically with pressure.

Effect of frequency

Of the many resins considered in this guide, weld frequency appears to have a significant effect only on unfilled Ultem PEI resin. Weld strengths corresponding to those of the virgin unfilled Ultem PEI resin can only be achieved at high weld frequencies.

Effect of amplitude

Weld amplitude by itself does not affect the welding process; the energy input into the process is determined by the product of the amplitude and the frequency.

Blends

Blends also exhibit the four phases of vibration welding.

Dissimilar materials

High strengths as high as the strength of the weaker of the 2 materials can be attained in vibration welds of some dissimilar materials. However, the conditions for achieving high strengths (threshold penetration) are different from those for neat resins. Although welds between dissimilar materials exhibit the four phases of welding observed in neat resins, high weld strength is not necessarily achieved once an apparent steady state has been attained. For example, in the welding of Lexan* PC resin to Ultem* PEI the apparent steady-state conditions indicated by penetration-time curves are deceptive because of differences in "melt" temperatures and viscosities. The process is dominated by the high melting and flow rates of PC, which mask the still-developing melt and flow conditions in PEI when an apparent steady state has been attained. Consequently, weld strength continues to increase even when this penetration falls in the steady-state regime. Because of this effect, additional information is required for optimizing welds between dissimilar materials.

Structural foams

Based on internal testing, very high strengths of Noryl M-PPO structural foam welds, very high strengths can be achieved in structural foam welds.

Weld strength

Measures for weld strength

As mentioned in Joining Section, joint performance and weld strength have many facets strength under static and impact loads, creep performance, and so on. While static strength, obtained by a tensile test in which displacement or strain or load increases at a uniform rate until failure is an important first indicator of weld quality, it is not the only measure. In some applications creep rupture may be more important, for which the time to rupture at different stress levels may be the appropriate measure of weld quality. Process conditions can have a large effect on the morphology of the weld zone, which in turn can affect impact performance. As such, in some applications, impact strength may be a more important measure of weld strength. The data on the performance of vibration welds is sparse, and most of it relates to tensile strength of welds.

One measure of weld strength is the strength of the weld divided by the strength of the virgin material in the same test, which will be referred to as the relative strength in metals welding this ratio is called the weld factor. Another measure that is a good gauge of the ductility of the weld, is to compare the strain to failure for the weld with that for the virgin material.

For any given set of weld process parameters, the highest weld strength for a resin is attained once the penetration exceeds the threshold penetration for that resin and the particular part thickness. However, this is not true of welds between dissimilar materials, for which penetration-time curves also display the four phases of welding but for which the weld strength can continue to increase even after an apparent steady state has been attained.

Fatigue considerations

In general, very little attention has been paid to the fatigue strength of thermoplastic welds. Some work has been done in understanding the fatigue behavior of hot-tool welds in polyolefin pipes caused by internal pressure cycling. Because of the sensitivity of the fatigue process to sample preparation and flaws in the material, the characterization of the fatigue strength of materials is known to require a large number of tests.

Residual stresses

The thickness of the weld zone is normally on the order of 0.25 mm (0.01 in). This zone is formed by the rapid cooling of a thin layer of molten resin, and can therefore be expected to have high residual stresses. While these residual stresses may not affect the static and fatigue strength of welds, local long-term creep could result in inducing cracks and failure. Also, these regions of high residual stresses are more prone to attack by solvents.

Residual stresses in vibration welds have not been characterized.

Processing

Introduction

The penetration thresholds recommended in this section are for parts with a nominal thicknesses of 6.35 mm (0.25 in) or less. The appropriate threshold for a particular thickness can be obtained by generating a penetration-time curve. The threshold is then the penetration at which a steady state is achieved.

Joint design

There are four elements of joint design

- Design for joining (welding)
- Design for strength
- Aesthetic considerations
- Fixture design

Because joining has not been considered important in the past, when welding is required, it tends to be considered after the part has been designed and the molding process chosen. By then it is often too late to incorporate sound principles of welding, resulting in a suboptimal weld or requiring a redesign of the part. Clearly, assembly considerations and joint design must form an integral part of the part design process.

The choice of the welding method depends on the part geometry, size, and functional requirements of the joint. For example, large parts are not suited for ultrasonic welding. While vibration welding is suited to welding large parts with near-flat seams, parts with complex joints or simple joints with out of plane features cannot be assembled by vibration welding. Hot-tool welding is suited for welding parts with complex joints. If disassembly for repair, to be followed by reassembly, is desirable, then an induction welding process may be the answer. However, when several welding techniques are candidates for the same part, the optimal joint design will be different for each technique. Thus part design should include weldability considerations such as suiting the joint size and shape to the process, placing the joint in areas of low stress, and locating the joint such that aesthetic requirements are met. Vibration welding requires flat seams, ideally along plane parting surfaces of injection-molded parts. The technique can accommodate stepped joints with parallel seams, and even joints with small out of plane curvatures.

Design for strength

Design for strength is based on the maximum achievable weld strength for a particular material. From the standpoint of joint design for structural applications, whether or not the weld can achieve the strength of the virgin material is far less important than knowing what the maximum achievable weld strength is. The joint area can be increased to compensate for any strength loss in the weld. This is no different from the procedure used for sizing a part to withstand given loads, wherein the part thickness is increased till the stresses in the part fall within acceptable limits.

In thin-walled parts, most joints are formed at near rectangular intersections. At such “T” or “L” joints, a good practice is to provide a small flange on one of the mating sections, as shown in figure 4. This strategy was used in the first successful all-plastic 8 km/hr (5 mph) automotive bumper molded from Xenoy* PC/PBT. The components mated by vibration welding an injection molded channel section to a molded back plate with small, molded-in flanges at both the weld interfaces.

Because adequate data are not available for weld performance under other loading conditions such as shear, impact, and creep all that can be done is to prorate the strength of the virgin material in the desired loading mode by the maximum achievable relative strength in tension.

Aesthetic considerations

Because of the nature of typical applications, aesthetic considerations are very important for most plastic parts. In very thin “T” or “L” joints there is a possibility of weld “read through” caused by differential shrinkage at the weld interface. This problem can be avoided by a local thickening of the appearance surface, as indicated in figure 5.

Another consideration is weld flash. Weld flash does not affect weld strength the weld zone is normally thinner than 0.25 mm (0.01 in) and could therefore be machined off for better surface appearance. However, that would add to the cost. The preferred solution is to mold in “flash traps.” These are small cavities on one or both mating surfaces at the joint interface into which the laterally extruding melt, that normally forms the flash, would flow. Different variations of flash traps are schematically shown in figure 6. The cavities are sized to collect the anticipated lateral flow which can be determined once the weld penetration level has been selected.

Design of fixtures

All welding methods require fixturing that is part and welding-technique specific. In vibration welding, one of the parts to be joined has to be vibrated relative to the other at a frequency of 100 Hz or higher. Therefore, this part should normally be the lighter of the two. The fixturing must be designed to hold the parts in such a way that the desired motion can be generated at the interface at the desired weld amplitude and pressure. This normally requires that each of the parts be effectively clamped as close to the interface as possible. Furthermore, the fixtures must be so designed that the desired weld pressure can be generated along the entire seam which may not happen if the force for generating this pressure is applied at discrete points that are spaced too far apart. Therefore, in demanding structural applications, fixture design requires a detailed analysis (e.g. using the finite element method) to ensure that the prescribed weld process conditions, such as the weld amplitude and the pressure, can be attained at all points along the weld.

Machine considerations

Types of machines

In commercial vibration welding machines, the moving half of the parts to be welded are vibrated by exciting a tuned, stiff-spring and mass system by means of an externally imposed oscillatory force. A schematic representation of the first commercial vibration welding machine is shown in figure 7 (Branson).

The moving part is attached to the upper fixture, which is attached to the stiff springs. The natural frequency of the system is determined by the stiffness k of the spring and the mass m_1 of the moving part, the upper fixture, and the springs. This spring-mass system is excited by means of two electromagnets 3, to generate the desired vibratory motion. The excitation force has twice the line frequency so that these machines operate at 120 Hz in the US and at 100 Hz in Europe. Later versions of these machines were able to double the frequency to 240 and 200 Hz in the US and in Europe, respectively. In the first version of this machine the magnitude of the excitation force was fixed, so the amplitude of the vibratory motion could only be changed by changing the mass m_1 . Also, in these machines a mechanical device was used to hold the vibrating parts under pressure. This made it very difficult to apply a controlled weld pressure to the part. However, machines are now available in which the weld amplitude can be changed without having to change the mass of the system, and in which a controlled weld pressure can be applied.

In an alternative design, an open-loop hydraulic system is used to drive the spring-mass system. This design makes it easier to obtain higher frequencies.

Figure 4

Preferred design to T and L joints.

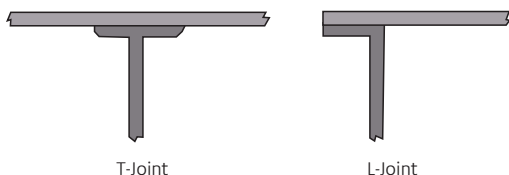


Figure 5

Increased local part thickness to prevent weld read through.

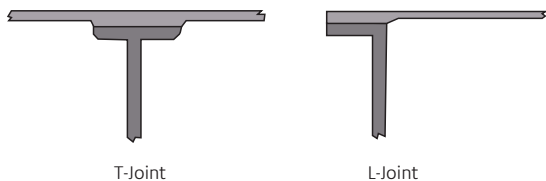


Figure 6

Flash traps.

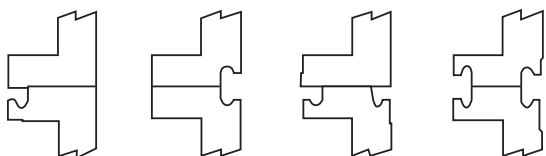
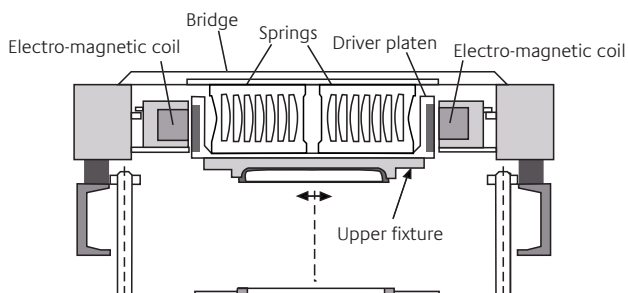


Figure 7

Schematic representation of an electromagnetically driven, tuned spring-mass system vibration welding machine.



Troubleshooting

A weld may not perform well for many reasons

- Poor weldability of the material - check data on weldability
- Weld process parameters chosen incorrectly - check recommended process parameters
- Poor joint design placed in highly stressed region or flexes in an undesirable way during welding, resulting in a poor weld
- Poorly designed fixturing, resulting in a nonuniform weld pressure and in an inadequate weld amplitude due to part flexing - carefully analyze the structural design of the fixture

Guide to the literature

A general overview of joining methods for plastics, in which the advantages and disadvantages of different joining methods are compared, is given in reference 1. This overview lists 259 references pertinent to different aspects of plastics joining.

Information relating to applications of vibration welding is available in references 2 to 6.

References relevant to the welding of the thermoplastics in tables 1 and 2 are listed, respectively, in tables 3 and 4.

References

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