Introduction to Plastics Processing & Machineries

When moulding must be ruled out. This situation would arise when the number of articles required is small and would not justify the expenses of a mould, or when complex features may not be achieved by moulding. The manufacturer would then be relying on machining and/or joining techniques to produce the plastic article. In these circumstances, standard stocks of sheet or bar material would be used and the fabrication procedures are generally similar to those commonly employed for metals and woods.

Indeed, even when the order for a component is large enough to justify moulding, it is not I unusual to machine a prototype so that the design may be assessed before large sums of money are committed on a mould.

It is apparent, therefore, that a significant proportion of the plastic industry is concerned with machining, joining and decorating plastics.

Machining of Plastics

In general the machining methods for plastics are similar to those used for metals. Most plastics can be machined with excellent results using conventional wood working machinery with slight modifications to the tools. There are, however, important differences in the way in which plastics react to machining. In the first place plastics have low values of thermal conductivity away so that only very little of the heat generated in the machining area will be conducted away through the material. If provision are not made to reduce the heat build up then a sequence of thermal expansion of the material, increased friction, increased heat build up, and increased tool wear can lead to a rapid deterioration in the machining process. Eventually localized melting of the material will occur and manifest itself in the form of bad surface finish and poor dimensional tolerances. Steps which may be taken to avoid excessive heat build up include the use of coolants, sharp tools, with adequate clearances and high rotational speeds with slow feeds. It must also be realized that plastics have relatively low module so that if the work piece is not adequately supported, it will deflect under the pressure from the cutting tool. This will lead to uneven cuts and poor tolerances.

Another important consideration for plastics is that their viscoelastic behavior will cause time dependent recovery from the strains induced during machining. Clearly the machining conditions must be selected so as to reduce these strains to a minimum. If this is not possible then the recovery should be taken into account when performing the final cuts. Under proper conditions plastic components can be machined to closer tolerances then are possible by moulding. For particularly accurate work the dimensional stability and toughness of the component will be improved by annealing the material prior to machining. The wide variety of properties and structures of plastics mean that the optimum machining conditions and tool geometry or each material can very widely.

Assembly Methods

In many situations, polymeric materials have to be joined together or joined to other materials as part of a fabrication process or to repair damage. There are a variety of methods that can be used, depending on the application, but the most common can be divided into three categories.

Adhesive Bounding

The use of adhesives offers the possibility of very strong bonds, although it is not a suitable method for all plastics and may initiate crazing in some materials. Welding can also produce strong bonds, but it may introduce stress concentration in the bond area. Both of these methods produce permanent joints, whereas mechanical joints can offer the possibility of disassembly. However, mechanical joints need to be carefully designed because the rivets or screws can introduce stress concentrations, and snap fits, although popular and convenient, may have limited strength. Therefore the choice of jointing method depends on the conditions imposed by the application. To assist in this selection each of the three techniques are described below.

Welding of Plastics

Most thermoplastics can be permanently jointed by welding. A wide variety of techniques are available and the choice depends principally on the materials to be welded, the geometry of the parts to be joined, and the strength required from the weld. Most of the methods are relatively simple so that joints can be produced quickly and economically. In some cases the strength of the weld is close to that of the parent material, but to achieve this the welding parameters such as temperature, time, pressure, and so on, must be optimized.

Hot Gas Welding

This method of welding was the first to be developed for plastics and is a modification of gas welding of metals. Basically the process involved melting the weld area by means of stream of hot gas supplied from a hand held torch. A welding or filter rod made from the same material as the parts to be joined is also used.

During the welding the weld bad and the welding rod are heated simultaneously by gently moving the hot gas stream back and forward between the two. When softening occurs, slight pressure is applied to the rod to feed it into the melt pool whilst steadily progressing along the joint. The welding torches are usually electrically heated and capable of providing a gas temperature of between 200^{o} C and 300 ^{o}C at the nozzle orifice. The gas should be dry and clear with a flow rate of 15-60 liters per minute at high pressure. Tests have shown that the type of gas affects the bond strength. Strongest bonds are achieved with oxygen where as carbon dioxide tends to produce weak bonds. In many cases the most convenient gas to use ICQ processed air since it is inexpensive and produce. Satisfactory welds. However several plastics, such as polyethylene and acetal, oxide very easily and re best welded using nitrogen.

Rigid PVC is the most suitable material for hot gas welding but other plastics can also be joined very satisfactorily by this method. The major advantage of this welding technique is that large structural shapes can be fabricated relatively easily, but it has the drawback of being a slow process relying on operator skill for good welds.

Ultrasonic Welding

The use of ultrasonic energy to weld rigid thermoplastics developed in the early 1960s. The principle of operation is that pressure is applied to the parts to be joined and ultrasonic vibrations are transmitted through the materials. The heating at the interface causes melting of the plastics and the pressure, which is normally under 1 MPa, produces a weld. A major advantage of ultrasonic welding is that strong joints can be produced in a few seconds. Most thermoplastics, including those with glass reinforcement, can be ultrasonically welded, but for some materials, such as acetal, nylon, polycarbonate, acrylic, and rigid PVC, good joint design is critical. In general, stiffer plastics are most suitable because they have lower damping and allow greater energy transmission to be joint. Since plastics can have a wide variation in structures and melting points it is preferable to produce welds between parts made from the same material. However, it is possible to weld dissimilar materials, particularly if they are compatible, for example, polystyrene and ABS or acrylic and ABS.

An ultrasonic assembly consists of a generator, which converts electrical mains frequency into ultrasonic frequencies, and a transducer, which converts this high frequency electrical signal into mechanical vibration. These vibrations are transmitted to the bond area via a horn which is usually made from titanium or aluminium alloy. The former is preferred due to its low acoustic loss, high fatigue strength and high strength to weight ratio. To provide maximum vibration amplitude at the joint area, the horn is operated in resonance and so it must be accurately machined and tuned for the vibration frequency used. Most generators provide an ultrasonic frequency of 20 KHz, and output powers can vary from about 300 W to 1 KW. It is not difficult to see why welds are produced in a matter of seconds when it is realize that at a frequency of 20 KHz, typical displacement amplitude of 0.06 mm at the north is equivalent to a relative displacement of 4.8 m in one second. For example, it is possible to put a metal insert into the plastic and this can be used for inserting metal hinges into spectacle frames. Another application for ultrasonic vibration is in the staking or riveting plastics to components made from different materials, particularly metals. Usually a hole in the metal sheet received a stud from the plastic, which is then melted and shaped using an ultrasonic horn.

Friction Welding

When two surfaces are rubbed together it is possible to generate sufficient heat to cause fusion welding between the materials. This is the basis of friction welding of plastics. The relative motion between the surfaces may be oscillatory or rotational, although the latter is usually more convenient. They are then brought into rubbing contract and axial pressure applied. When melting has occurred at the interface, rotation is topped but the pressure is maintained to consolidate the weld during cooling of the material. In some cases a boost pressure applied during this latter stage may benefit the strength of the weld. Good weld strengths may achieved quickly and simply by this welding method.

The important variables in spin welding are the relative surface velocity, pressure, and duration of the rotational phase. By the nature of the process the components usually have a circular least one of the components is symmetrical about its axis.

The low thermal conductivities of thermoplastics means that they are particularly suitable for friction welding and most of them can be joined satisfactorily by this method. In some cases dissimilar plastics can also be joined, but the weld strengths are usually less than 50 per cent of the parent materials.

High Frequency Welding

In this welding method the two sheets to be joined are clamped between two metal plates and a high frequency field is passed between the plates. If the dielectric loss of the plastic is high, sufficient heat can be generated to melt the plastics at their interface. By applying is high, sufficient heat can be generated to melt the plates the plastic sheets can than be welded. This technique is most widely used for PVC film. Other plastics can also be used but if their dielectric loss is then very high frequencies, and hence more expensive equipment must be used.

Normally the frequency used is in the band 27.12 MHz + 0.6 per cent. The platens, which can be large (2 m x 1.5 m) must be parallel to quite close tolerances and capable of withstanding pressures upto 1.2 GPa. Platens are usually pneumatically or hydraulically operated with facilities to control the applied pressure, the stroke, and the weld time.

Hot Plate Welding

There are several techniques, which utilize a heated tool to weld plastics. The most commonly used method is hot plate welding in which the parts to be welded are pressed against a heated plate and subsequently pressed together to produce a fusion weld. The technique is ideally suited for butt-welding. The heated metal tool usually has a PTFE coating to prevent the melted plastic from sticking to it. Strong joints can be produced in most right thermoplastics, and experiences has shown that the process variables that is, tool temperature, weld pressure, weld pressure, and weld time, are not critical within reasonable limits. In some cases annealing of the weld zone will enhance the weld strength.

Mechanical Joints

In some applications the permanent nature of the joints produced by adhesive and welding technique is undesirable. In such cases mechanical fastening techniques may be used to give recoverable joints. Indeed, the advantages offered by mechanical joints in terms of speed of assembly, wide applicability, and cleanliness may make them preferable to other techniques irrespective whether permanent or recoverable joints are required. There is a wide variety of methods available ranging from conventional techniques such as riveting and screwing to techniques such as integral hinges, which utilize the unique properties of certain plastics.

Decorating Plastics

There are very few plastic components, which do not require some from of decoration or surface marking. This can vary from simple requirements such as integral colouring or a textured surface to more sophisticated in-mould or post moulding techniques to produce a surface pattern. The reason for the surface pattern may be functional (for example, printed circuit boards), or as an aid in advertising (that is, to provide a product image), or simply for aesthetic purposes.

A wide variety of techniques exist for decorating plastics, and the choice depends on the material and the desired end effect. Not all methods are suitable for all plastics, and some methods require surface preparation, which may not always be economic or desirable. The main methods which may be used, for decorating plastics are described here.

Integral Colouring

A major advantage of plastics is the ease with which they can be given a permanent, through thickness colour by mixing pigment with the feedstock prior to, or during moulding. In the majority of cases the articles produced have a single colour, although special techniques are available for producing multi-colour components. Typical products of this type are keys for typewriters, calculators, digital telephones, and so on. Several techniques are available for producing multi colour mouldings, but the most common method is to inject the first colour from one barrel into the mould cavity and then have the mould rotate so that the second colour can be injected from another barrel and so on. For push buttons, the first shot would produce the outer shell of the button leaving the impression of the letter or numeral to be filled with the second colour.

Recently techniques have been developed to produce consistent marble effects in mouldings. It is also worth nothing that the surface appearance of plastics is often improved and made more serviceable by embossing or texturing the mould used to produce it.

In-mould Transfers

It is possible to decorate plastics by placing a transfer containing the printed design in the mould at some stage during the moulding operation. This technique was originally developed for decorating articles made from thermosetting materials. When the article is partially curved the mould is opened and a printed transfer impregnated with the same thermosetting material is placed between the mould and the article. The mould is then closed and the cure allowed to continue. The pattern here becomes an integral part of the moulding and is not susceptible to damage. This procedure may also be used in the production of decorated reinforced plastic components.

In recent times in-mould transfers have also been successfully for thermoplastics. In this case the patter is printed on or laminated between thin sheets of a material compatible with, the material being moulded. This transfer is placed in the mould and when the melt is injected pattern becomes an integral part of the moulding and is not susceptible to damage. This procedure may also be used in the production of decorated reinforced plastic components.

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Post – Moulding Techniques

Printing

At first glance it may seem ridiculous to even consider painting plastics. However, there are a number of situations where this is an attractive proposition. In the first case, paint may be used to cover moulding defects, for example, weld lines, splay marks, or reinforcing fibres. This is often the motive in automobile components such as fasica panels where appearance is extremely important. In other cases, paint may be used to improve the weatherability of a plastic by protecting it from moisture and UV radiation. Again, the automobile industry has recognized this advantage by painting plastic bumpers and grilles. Another important reason why plastics might be painted would be to provide the designer with greater scope for multi-coloured components. It is clear, therefore, that painting is a possibility that should not be overlooked by the designer. Conventional painting methods, and in particular spraying, may be used successfully on a range of plastics. However, plastics can vary considerably in the ease with which they will accept a paint coat. Cellulose acetate and the styrene-based materials are the easiest to paint whereas the polyolefin and thermosetting materials are among the more difficult. Various forms of surface preparation are available for easing painting problems. For example, mould release agents particularly the silicone type should be removed before any painting is attempted. Apart from general cleaning and degreasing, the difficult materials may also require surface treatment, which will improve adhesion of paint. Techniques to do this include light abrasion, etching or producing an oxidized surface. For the difficult plastics the use of priming costs, which adhere well to the plastic and provide a good surface for subsequent paint coats, is also advisable.

One of the last techniques for painting plastics is electrostatic painting. Effectively, the paint and plastic are oppositely charged to create electrical attraction. This is done by imparting a high voltage charge 10 the paint particles and grounding the pat to be painted. Of course the plastic part to be painted must first be rendered conductive and this is usually achieved, by pre-treatment with ionized salt solutions. The advantage of this method of painting is that there is very little over spray or paint loss. The electrostatic attraction causes all the paint particles to be attracted to sides, back, and recesses in the plastic part. A limitation is that the process does not lend it self to mask painting, where only part of the plastic is to be painted.

Hot Stamping

In this method plastic part to be decorated is firmly supported and a coated foil from a roll is placed over it. A heated metal or rubber die containing an impression of the desired design or lettering is then pressed down on the foil. In a very short time (typically one second) a thin skin layer on the plastic component melts and the coating on the foils used consists of several layers. There is a backing firm, usually made of cellulose acetate or polyester, which is coated on one side by a heat sensitive release agent. This in turn coated with a pigmented metal film and finally a heat activated size adhesive to promote good adhesion to the plastic component.

As an alternative to having the desired engraved on the die it is possible to have the pattern on the foil and the use a die with a plain face. This has advantage that a multi-coloured pattern can be transferred in a single operation. Overall, hot stamping is attractive because it is a dry, clean consistent way of decorating plastics.

Metallic Coatings

Various techniques are available for coating plastics with a metallic layer. This type of composite has a number of advantages over a solid metal component, particularly as regards weight saving, corrosion resistance, and reduced costs. Plated plastics have a substantial market in the plumbing and bathroom fitting industries. Taps and shower fittings are frequently moulded in ABS, which is then metal plated. Other applications include consumer durables such as refrigerator and washing machine fittings, clock and camera housings and so on, and fashion articles such as buttons, buckles, jewellary and the like.

The main methods used to put a metal coating on a plastic are electroplating and vacuum metallizing.

Electroplating

This is method is similar to the electroplating of metal parts. The plastic component to be coated must be carefully cleaned and etched to improve adhesion of the metal layers. As part of this pre-conditioning, seeds of palladium and tin (catalyst particles) are deposited in the surface pores of the plastic to assist the next stage of the preparation. Since plastics are non-conducting it is necessary to deposit a conducting layer on the surface of the plastic before it can be electroplated. This is done using a process known as electroless metal deposition. Nickel or copper are chemically reduced from solution and deposited on the catalysed surface. The final step is to make the part to be coated the cathode of a electrolytic cell. The metal to be coated is the anode and metal gradually dissolved and is deposited on the cathode (the plastic component). Any sequence of metal layers may be used. It is usual to use copper or nickel for the first layer because it can act as a cushion capable of accommodating the differential thermal expansion between the plastic and the final metal coating (usually chromium). The metal layers are then kept thin (copper/ nickel 0.02 mm and chromium 0.0003 mm) for reasons of economy and also to avoid stressed in the system. ABS and polypropylene are the most common base plastics for this type of metallic coating process.

Vacuum Metallizing

In this process the plastic part to be coated is firstly sprayed with a lacquer to promote adhesion of the metallic layer. The part is then mounted in a jig and placed in a vacuum chamber. When the necessary vacuum has been achieved, small pieces of metal wire, usually aluminium are heated in the vacuum causing them to evaporate and be deposited on the plastic component. To ensure a uniform coating on all the areas of the component by spraying a protective lacquer layer on to the aluminium. This technique has proved particularly suitable for materials such as ABS, polystyrene, acrylic, and polycarbonate, whereas the polyolefins are less receptive to this type of coating.

Printing

Many printing processes similar to those used for producing patterns on paper and cloth can be used for plastics. In screen-printing, for example, a nylon or polyester, stencil is supported on a wooden frame. It is placed over the area to the printed and when a rubber or plastic blade is pulled across the screen, ink passes through the mesh and on the plastic. Originally a drying stage was necessary but now a day fast drying inks are available. Multiple colours can be applied in a single pass and most plastics can be decorated in this way. In dry offset printing the ink is applied to image plates from which it is transferred to a printing surface and eventually to the product. In flexography the pattern is transferred directly from a rubber plate.

In most of the printing techniques the adhesion of the ink is very good because it fuses into the plastic. The reason for this is that the inks are specially formulated to attack the surface of the plastic on a microscopic scale and embed pigment in the shape of the desired pattern. Consequently, ordinary printing inks for paper or cloth are not suitable for plastics and, indeed, special inks are needed for each plastic. The choice of solvent carrier for the ink pigment is very important because excessive chemical attack of the plastic could have detrimental effects on properties. In the same way, some plastics are very resistant to solvent attach and special surface pre-treatment is needed before any printing can be performed.

Reference book:

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