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POLYMER JOINTS

Balázs MARCZIS and Tibor CZIGÁNY[1]

Department of Polymer Engineering and Textile Technology
1Faculty of Mechanical Engineering
Budapest University of Technology and Economics
H-1111 Budapest, Műegyetem rkp. 3., Hungary
e-mail: czigany@eik.bme.hu

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Abstract

Parallel to the spreading of polymers as engineering materials the spreading of polymer joints can be observed. Similarly to metallic joints, according to operational principle joints working by force, by shape or by material layer can be differentiated in case of polymers, too. The aim of this paper is to review different joints emphasizing the most frequent type, the welding one. To reach a reproducible welded joint a computer controlled welding stage was built. The weldability and the joint efficiency factor were investigated at the most frequently applied polymers. It is managed to determine an optional welding speed that highly varies depending on the molecular structure of the type of polymers.

Keywords: polymer joint, welding, joint efficiency factor, acoustic emission.

1. Introduction

The present high level of the manufacturing technique and of the production of polymers and press-casting tools make it possible for designers to develop products without any limitation except for their imagination. Products having complicated geometric shape and the simpler ones are usually designed from separate elements, that is designers should choose the best technique to joint elements into structures concerning both functional and economic points. The aim of this paper is to present different techniques applied to joint polymer elements, especially welding, emphasizing the hot-gas welding process.

2. Theoretical Background

Joints for polymer structural elements can be classified according to the operational principle of their effect, that is they can transfer load by force, by shape or by continuous material layer. On the other hand joints can be differentiated on the basis of the way how they can be separated: there is a destructive or a non-destructive one [1].

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[1]author to whom correspondence should be addressed

2.1. *Joints Transferring Load by Force*

These joints transfer load by the friction force generated between elements at assembling. One characteristic representative of this joint is the threaded one. To connect polymer products there are several types of threaded joints. In case of small loads, joint elements are usually connected by self-cutting metal screws. Load carrying capacity in these joints is determined mainly by the thread geometry parallel to the proportions of the plastic 'eye' or 'tube' shape as an integrated part of the polymer element (*Fig. 1*) [2]. In case of bolted joints the most frequent construction is the metallic nut inserted in polymer element making profile, too (*Fig. 2*). The load carrying capacity of these second type joints is considerably higher than the joints produced by self-cutting screws. The high load carrying capacity is guaranteed by the considerably large contact surface between an inserted nut and a polymer element. These inserts are pressed into plastics by pneumatic or electric press. Another method applied widely is the ultrasonic device to press inserts into thermoplastic materials. The vibration generated by the ultrasonic device shall produce a 'melted' phase in this vicinity making it possible to fit the insert that is suitable for assembling after cooling down. Using specially constructed inserts no devices mentioned are necessary.

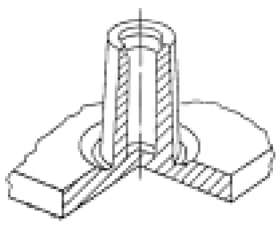

Fig. 1. Plastic 'eye' or 'tube' shaped up to connect self-cutting metal screws

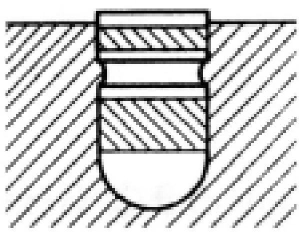

Fig. 2. Metal insert into polymer element to join metric bolts

2.2. Joints Transferring Load by Shape

The characteristic of these types of joints is that geometric shape transfers the load further classification that makes possible.

2.2.1. Snap Fits

A frequent method especially in case of polymers is to joint elements by shapes that pop into each other. All snap fits can be characterized that jointed elements meet with some interference provided by elastic deformation at assembling. The connected elements return to stress-free state. The snap fits can be joints possible to separate by non-destructive or only by destructive method. Snap fits possible to separate by non-destructive method give less connecting force comparing to the others that are possible to separate by destructive method or using special tools (*Fig.3*). Snap fits are economic only at high scale production owing to their expensive tools. The advantage is that they can be assembled in a quick and simple way.

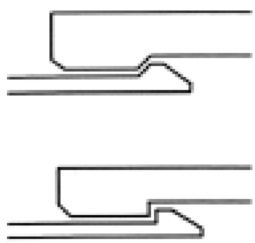

Fig. 3. Characteristic shapes for snap fits for detachable (upper) and non-detachable joint (lower)

2.2.2. Riveted Joints

The advantage of riveted joints is that elements made of different engineering materials can be mated. The technology is quick and simple, but its load carrying capacity is significantly lower than that of the previously mentioned joints. A further disadvantage is its non-esthetic appearance limiting the competitiveness of the product. The most frequent construction of riveted joints for polymer elements is when the rivet shank is an integrated part of the element while the holes are shaped up in the mated part. After mating these elements, the riveted joint can come into being under pressure causing plastic deformation to shape up the closing head

(*Fig. 4*). Applying the classical riveting technology this joint is applied typically in case of thermosetting polymers using rivets from non-ferrous metals.

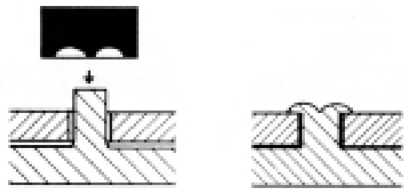

Fig. 4. Closing head on rivet shank is formed by hot tool pressed on it

2.3. *Joints Transferring Load by Continuous Material Layer*

The two classical types of these joints are the glued and welded joints. Nowadays owing to the newly developed intelligent engineering materials a new type of joint, the intelligent joints have appeared.

2.3.1. Glued Joints

Glued joints connect two elements by applying glue between them. Load carrying capacity of glued joints is influenced by the cohesive forces of the glue as engineering material and adhesive forces developing at the interfaces of the structural element and the glue. The perfect-glued joint is constructed so that the grade of adhesive forces can be compared to cohesive ones. In other words the properly shaped glued joint will be damaged by the fracture of the basic material and never by separation at interface [2]. Glued joints can be primarily used at shearing. The disadvantage of glued joints is that mated surfaces should be carefully cleaned before joining them.

2.3.2. Welded Joints

The essence of welding technology is to create cohesion between elements to be connected. Similar to welding technology applied to metals [3], in case of polymers high load carrying capacity joint can be created by local heat invention. The well-known structural differences of metallic and plastic materials raise a series of problems [4]. The welding technology requires melted basic materials giving possibility to join the chain-molecules. But in case of thermosetting polymers the previously shaped up molecular-chains are special and cannot be melted again, therefore they are not weldable. The thermoplastic polymers are weldable ones only where chemical chains are linear or do not have ramified branches. Therefore at these thermoplastic polymers the welded connection can be shaped up by applying parallel heat and press using locally additional welding sticks or not. As a consequence of basic requirements of welding the connection can come into being in case of free movement of particles, that occurs in liquid phase. This situation can be reached by increasing the temperature, let the Brown-movement of chain-molecules grow in a measure being able to break secondary connections among chain-molecules and let them independent from each other, and this practically means the liquid phase. The value of joint efficiency factor is higher, if the density of connection among chain ends is deeper and higher. To obtain high quality welded joint in polymers the common optimum of four parameters should be ensured:

i. Equivalent structures of molecules.
ii. Temperature guarantees the proper viscous and elastic physical states within an optimal interval.
iii. To keep pressure high enough to produce the required distance between surfaces to be welded.
iv. Cooling the welded joint to reach state of load carrying.

The everyday engineering practice uses polymer welding for joining tubes and/or packing foils though thanks to development of technology this technique is more frequently applied to shape up load transferring joints. According to the way of heat transfer, the most important welding technologies are the following [2, 5].

2.3.2.1. Heat Convection Technologies

The essence of heat convection technology is that area of welded seam will be heated up by heat conduction or by heat convection to reach the proper rheological state.

Hot-gas welding is a technology using hot-gas flow (air or inert gas) to heat up basic materials and welding stick along the seam.

Extrusion welding is similar to hot-gas welding as it heats up the premanufactured seam-profile by hot-air blowing while the welding stick will be added in extruded phase as a a separately melted one.

Hot plate welding applies high temperature metallic element pressed between the elements to be welded that after melted partially will be pressed to each other. This technology is generally used for tube welding.

Welding with heated wedges. This technology is a continuous variant of hot plate welding applied mainly in case of soft PVC and PE foils. The electrically heated wedges are controlled both in temperature and power.

Welding with heat impulses heated directly the overlapped foils along the seam then put an end to heating applying press.

2.3.2.2. Welding by Radiation

Welding by laser irradiation is a new technology in case of polymers. To generate the melted state of the polymer the required heat, similar to the technology used in case of metals, is supplied in highly concentrated form directed straight to the spot. The greatest advantage of this technology is that it is precise, easy to automatise and the heat-effected area is minimal.

2.3.2.3. Processes Applying Direct Heating

Spin welding utilizes friction heat generated on a centrosymmetric element by friction. The rotating element is pressed against a stationary one so that friction power turning into heat will melt the surfaces of elements. At the time required rotation is stopped, the elements – cooling down quickly – are connected.

Welding by vibration is a technology similar to rotation welding as the necessary heat is generated from friction power at this technology. The elements to be welded are pressed against each other and the heat is generated by small translational motion. After stopping the motion, elements are jointed.

Ultrasonic welding utilises energy of vibration. The material turns into melted phase owing to friction on interfaces of molecules. The method requires high frequency (20–50 kHz) power source. The specially shaped surfaces are touching each other then after 1–2 sec generation surfaces are melted and after switching off generation they are welded together.

2.3.3. Intelligent Joints

Research fellows at the University of Illinois (Urbana-Champaign) utilising a brilliant thought have developed a polymer able to regenerate and to repair oneself continually by activating capsules in it. The model of the self-curing capability was the human body. Intelligent joints have two important characteristics. The one is the automatism the other is the place-specific nature, that is curing material should be equally distributed but it should be activated where it is necessary. The problem has been solved by mixing the activator to the monomer so that components have been enclosed into sphere-shaped microcapsules. Besides this activator, a catalyser was added to help monomers organize into polymers. The cracks generated in polymers open the capsules and the liquid phase monomer pours into cracks, where – owing to the presence of catalyser – it organises into polymer and finally by phase changing turns into solid. That is the material cures itself automatically generating new joint acting by continuous material layer (*Fig.5*). Due to this newly developed method the service life of engineering materials can be elongated significantly. The critical point of this method is to select the wall-thickness of capsules properly. It should be strong enough to survive without any damage of the polymerisation, but it should be permeable, let the micro-cracks through and do not allow them to go round [6].

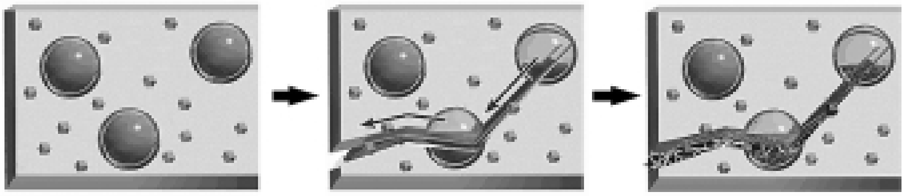

Fig. 5. Capsules, as cracks come into being, open the monomer flowing into microcracks in the presence of catalyser start polymerisation

3. Experimental

3.1. Tools

Our aim was to automate the manual hot-air blow welding technology making the welded joint better concerning both its load carrying capacity and reliability, parallel to develop a reproducible technology. The joint efficiency factor at hot-gas welding is influenced by three basic parameters: the welding temperature and velocity, as well as, the pressure applied. To obtain perfect welded joint, all the three parameters should be optimized. To fulfil all these requirements an electrically operated computer controlled measuring stage have been designed and realised for the LEISTER type hot-air blow manual welding device solving the control over all the parameters at welding parallel to its reproducibility (*Fig.6*) [7].

Fig. 6. Computer controlled hot-air-blowing welding device

This welding stage follows a rectilinear motion over two rails and 4 coaches. It is operated by power screw supported in two Y-type rolling bearings and powered by a 0.55 kW electric motor. The shaft speed of the electric motor is controlled by a frequency converter. The coplanarity of rails is solved by a fine-polish granite sheet. There were 5 different materials (Poliamid-6 – PA6, Polycarbonate – PC, Polyethylene – PE, Polypropylene – PP, Polystyrol – PS) tested to be welded with 5 different welding speeds (40, 60, 80, 100, 120 mm/min). After welding, standard dumbbell specimens (DIN 50455) have been manufactured so that uncertain parts (start and/or end) of the seams were omitted.

The dried specimens have been tested on ZWICK Z020 type tensile machine at room temperature applying 10 mm/min tensile speed. 5 piece series from each material were tested. Test results have been evaluated by omitting the max and min values and inclination from average was a 95% confidence interval [8].

3.2. Determination Joint Efficiency Factor

In *Fig. 7* the welding speed dependent characteristic of PA6 can be observed and changes of joint efficiency factor for five types material can coincide with the structural characteristics of tested materials. The crystallic materials can be welded easier while amorphous ones show weaker welding characteristics. It can be explained by the more plastic behaviour of amorphous materials causing a slowlier melt followed by quick degradation. A quality order can be observed in both groups of materials from better joint efficiency factor to worse (crystallic materials: PE, PP, POM, PA6, PET- amorphous materials: PC, PS, ABS) correlating with the melting point of the materials. That is the lower the melting temperature is, the better the weldability of the material is. This characteristic can be explained that the smaller the difference between welding and environment temperature is, the more stable the melted phase is and it is easier to reach even temperature distribution. In case of investigated amorphous polymers air bulbs came into being along the joint and in its vicinity among to the started degradation of them (*Fig.8*).

3.3. Acoustic Emission Tests

Acoustics emission (AE) method as a test is based on the fact that solids subjected to mechanical or heat loads emits stress-waves from areas where physical changes had happened. The stress waves are generated when during deformation or break in solids energy is emitted and goes through the solid. The stress cannot be heard, but the effect generated can be. Irregularities can be: in case of metals the quick slippage along crystalline interfaces, reorganization of crystalline structure, crack propagation; in polymers the deformation or the crack of matrix, separation of glued interface, irregularity in the joint or in fiber reinforced polymers the local breaking of fiber, or fiber pulling out and debonding [9].

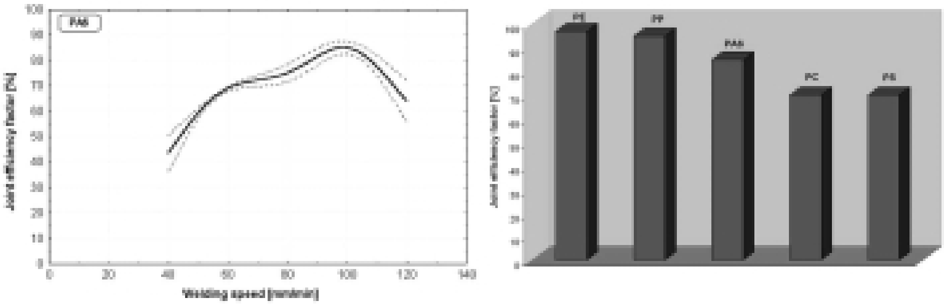

Fig. 7. The joint efficiency factor as function of welding speed (left). The average of joint efficiency factors for the investigated five materials (right).

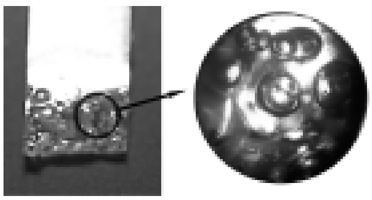

Fig. 8. Bulbs generated during welding in PC as macro- and microscopic images

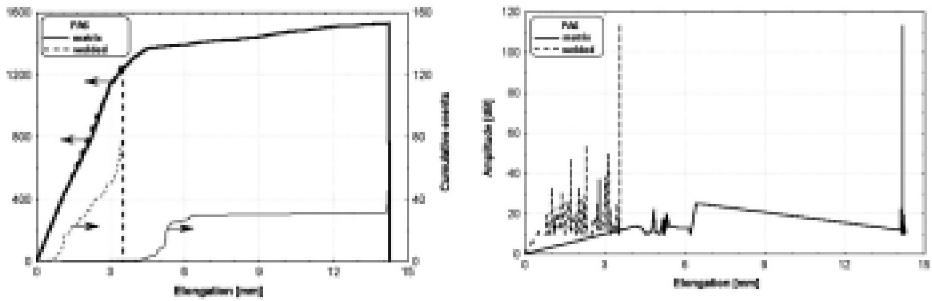

Fig. 9. Results of AE tests carried out on PA6

Parallel to tensile tests detectors of acoustic emission were applied. The AE measurements have been carried out both with welded and non-welded PA6 specimens to collect reference data on parameters of emitted stress waves characteristic of basic polymer. Comparing these results showing the events characteristics on welded specimens it was possible to determine that welded samples were acoustically active at the beginning of test keeping their higher activity till breaking. The basic material produces at about 20 dB high signals at the beginning of contraction but later at breaking the $\sim$ 115 dB signals were easily detectable by human ears, too. The values at welded specimens are higher at the beginning ∼ 50 dB but at breaking it remains on the level of basic material ∼ 115 dB (*Fig.* 9).

As a consequence of these results it can be stated that stress waves emitted from matrix or from welded joint by acoustic emission measurements can be well differentiated. That is acoustic emission tests are suitable to investigate welded joints, as when loading them acoustic activity can be experienced.

4. Summary

Operational principles of different joints applied to connect polymer elements have been investigated. Their operational principles can be load transmission by force, by shape or by continuous material layer like in metallic elements. The most frequently applied welded joint was the main target of this investigation. A computer controlled welding stage had been created for hot-gas welding to investigate the effect of welding speed on joint efficiency factor. Tests carried out proved the existence of an optimal welding speed where the seam is well reproducible, but the speeds are different in case of different polymers. It was also determined that weldability of polymer is highly influenced by the molecular structure of the polymer.

Acknowledgements

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