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Influence of the welding parameters on the structure and mechanical properties of vibration welded joints of dissimilar grades of nylons

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ABSTRACT

Because of very attractive mechanical properties, nylons make interesting group of materials, used in many engineering applications. Vibration welding is a welding method used to join various kinds of thermoplastics. Almost 15% of all welds of thermoplastics are made with the use of vibration welding. The ability of vibration welding of different kind of polymers may present cost advantage over the other welding techniques and may allow to produce elements of lower weight and of a high quality. This work presents results of vibration welding of dissimilar materials joints made of nylon 66 (PA66) and 30% glass fibres nylon 66 (PA66 GF30). The aim of the studies was to determine the influence of the welding conditions on the quality of vibration welded joints. The quality assessment was done on the base of tensile tests and microscopy examination, conducted on light microscopy and scanning electron microscopy (SEM). Results of the tensile test indicate that it is possible to achieve good quality of joints at the proper welding conditions. The light microscopy examination showed that the welding parameters influence the orientation of the glass fibres in the weld zone, on the continuity of the material in the weld and on the thickness of the weld. The results of the SEM indicate that the vibration welded joint is formed as a result of joining of the matrixes of two welded nylons.

1. Introduction

Linear vibration welding is a method of friction welding successfully used to join many kinds of thermoplastics with advantages which include short welding cycle, relative simple equipment, lack of additional materials and substance introduced into the weld zone, no surface preparation prior to joining, possibility of joining of similar and dissimilar materials (plastics, ferrous and non-ferrous materials, and even wood). The process works by clamping two parts together under pressure and rubbing with a specified amplitude a (usually in the range of 0.5–2.5 mm), frequency f (usually 100 or 240 Hz), generating frictional heat in the weld zone [1]. The process can be divided into four distinct phases: PI—solid friction heating, PII—unsteady-state melt friction, PIII—steady-state melt friction, PIV—solidification. The welding process, described by the schematic penetration–time curve is shown in Fig. 1. In the first phase (PI) an initial heating (to the melting temperature) at the interfaces is realized by Coulomb friction [2]. In this phase there is no penetration between welded elements. The second phase (PII) starts when the interfacial material begins to melt and flow outward in the lateral direction to the vibratory motion.

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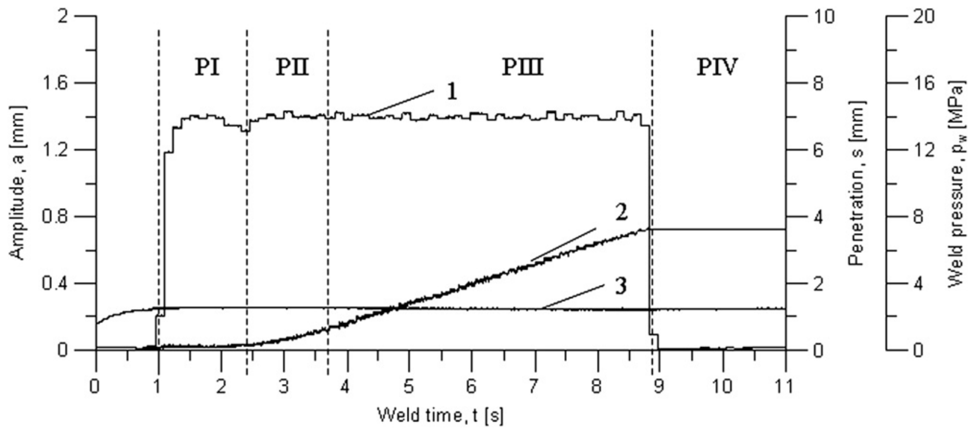

Fig. 1 – Runs of the welding parameters: amplitude *a*—1, penetration *s*—2 and the weld pressure p_w—3 as a function of the weld time *t* [s]. PI—solid friction heating phase, PII—the unsteady-state melt friction phase, PIII—the steady-state melt friction phase, PIV—solidification phase.

Because at the beginning of this phase, the thickness of the melt layer is initially very small, the shear rate is very high and the material outflow is also very small [3]. As the process goes on, the thickness of the molten material increases because of reduction of the shear rate, what causes an increase of the material outflow. The third phase (PIII) is reached when the melting rate of the solid equals the rate of the out flow of the molten material [4]. In this phase penetration increases linearly with time, and the penetration has a state value. In the last—fourth phase (PIV) the vibratory motion is being stopped. Under the constant pressure the molten material still flows from the welding area until it cools down [1–4]. The welding process ends when the material at the welded interfaces solidifies completely and then the weld is being obtained.

In many research centres [5–8] investigations of the influence of the welding parameters: the weld pressure, the penetration, the amplitude and the weld time on the weld strength of joints were performed. Investigations concerned of welding of homogeneous materials joints made of nylons 66, nylon 6 and their composites, 30% glass fibres reinforced. On the basis of the results it was found that the weld strength in the highest degree depends on the value of the weld pressure and then of the melt-down (penetration). Authors [5] had presented results which indicate that the tensile strength of joints made from 30% glass fibres reinforced nylon 6 and of joints made from 30% glass fibres reinforced nylon 66, made with the weld pressure 0.8 MPa, was greater than for joints made with the weld pressure 4.0 MPa. During another investigation of welding of semicrystalline polypropylene [5,7,9–11] it was found that mechanical properties of joints may be connected with the weld's structure. With the use of polarisation microscopy examination authors have noticed that there are four distinct regions in the weld. The region which is closest to the fusion line, undergoes a rapid cooling and does not have any visible spherulitic structure. It may indicate on the amorphous morphology. It may be caused by rapid cooling due to a large heat loss by conduction [12]. The next region as we move away from the fusion line shows "transcrystalline growth region". The last fourth region is indicated as the "deformation zone". The spherulites are very small because of the rapid cooling. The last region is the bulk material in which the spherulites are greater in comparison with those in the transcrystalline region. Researchers indicate that the weld pressure may have the influence on the weld structure. If the weld pressure is too high, the transcrystalline zone may not occur [7,10]. They also claim that such welds characterize of a worse weld strength. Investigations concerning welding of the glass fibres reinforced nylons were also performed [5,10]. Results of these studies indicate that orientation of the glass fibres in the weld zone affects the weld strength. If the weld pressure, during the welding process, is too high the weld zone is narrow and the glass fibres align with the melt flow direction. But if the weld pressure is appropriately low, the melt zone thickness is larger, compared to the fibre length. It results that the glass fibres can move in the other directions than the melt flow direction. In such conditions the glass fibres can align perpendicularly to the melt flow direction. Some of the glass fibres may cross the fusion line which may cause increase of the weld strength. Vibration welding technology enables welding of dissimilar materials. The best results may be achieved if the melt temperatures of both materials do not differ more than about 40 °C [10]. In case of welding of different materials, when one of them is glass fibres reinforced, orientation of them in the weld zone affects the quality of joint [5]. It was noticed that the strength of joints is higher if the glass fibres cross the fusion line [7]. Investigations concerning of welding of dissimilar nylons PA6 to PA66 showed that the welding parameters, the weld pressure and penetration, influence the quality of joints [8,13]. Studies were conducted with the weld pressure which was in the range of 0.66–5.80 MPa and the penetration was in the range of 0.3–1.7 mm. It was found that joints of better tensile strength were achieved in case of welding with the low weld pressure: 0.66 MPa. The tensile strength of these joints was on the level of 80% of the tensile strength of nylon 6 and 70% of nylon 66. In case of welding with weld pressure 4.7 MPa the tensile strength of these joints was on the level of 44% of the tensile strength of nylon 6 and 39% of nylon 66. Because of the different melting point of welded materials, Differential