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Vibration welding of polypropylene-based nanocomposites – The crucial stage for the weld quality

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ABSTRACT

Thermoplastic nanocomposites used for vibration welding are compounded on a twin-screw extruder by dilution of a concentrate masterbatch containing 14 vol% of filler. They are butt welded under different weld pressures by a linear vibration welding machine. By means of a quick ramp-down technology, this machine enables a very short vibration damping time of about 40 ms. The influence of different damping time on the weld strength of various materials is investigated. The experimental results are compared also with the results of simulation. In the case of nano-silica filled polypropylene, no impact of the damping time on the weld quality is detected and the possible reasons for this observation are explained.

1. Introduction

In the last decade, polymer-based nanocomposites have received a great deal of attention from industry and academics as well. The expectations are aimed at improving properties, such as mechanical properties, thermal conductivity or permeation of thermoplastic materials used for different components like fluid reservoirs or air intake systems [1–4]. However, very often the final component arises only after a final welding step. It is well known that this step is crucial for the mechanical behaviors of the component. Even if the welding process is well understood in case of welding of non-filled thermoplastics. Here is almost no profound knowledge regarding the welding of thermoplastics filled with nano-sized fillers.

Vibration welding is a well-developed technology for joining thermoplastics and thermoplastic composites since the last three decades [5–11]. The investigations on vibration welding have shown that the meltdown of the weld parts presented a uniform development during the whole welding process independent of the weld parts geometry, the materials and welding parameters, which can be divided into four distinct phases [5,6,12], as is shown in Fig. 1.

1.1. Phase 1

Solid friction, in which the meltdown is almost zero and the interface heats up to the melting temperature by Coulomb frictional heating. However, a thermal expansion will be expected in this regime.

1.2. Phase 2

Unsteady state of melt generation, in which the interface begins to melt, and resulting in unsteady flow in the lateral direction.

1.3. Phase 3

Quasi-stationary melt generation, in which a steady state is obtained such that the inflow rate of the melt from the bulk material into the weld area equals the outflow rate of the melt from the weld. A linear increase of the meltdown can be observed in the meltdown-time curve. As reported by Schlarb and Ehrenstein [13], accomplishing of this regime is an imperative requirement to obtain the best weld quality.

1.4. Phase 4

Cooling and solidification, in which the vibratory motion is stopped and in the same time the melt cools and solidifies. After

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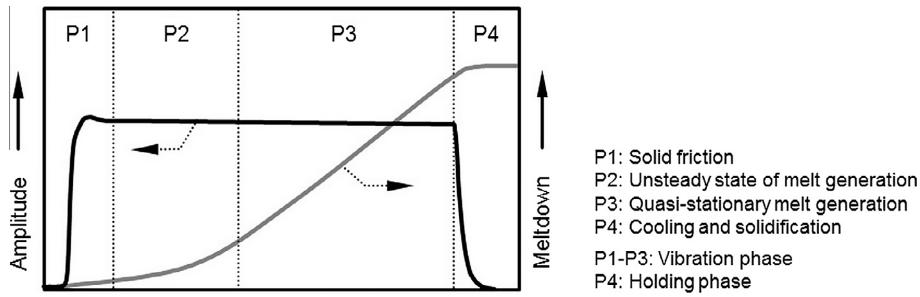

Fig. 1. Schematic representation of the time-dependent development of amplitude and meltdown.

stopping of the vibration, the vibration head requires time from the peak amplitude to a total standstill. This damping time may affect the weld morphology and, as a consequence, the weld quality. The impact of the damping time is dependent of the materials, component geometry, welding parameter and machine.

The cooling time of the polymer melt from the real-time temperature in phase 3 to the crystallization temperature after stopping of vibration might be also a crucial factor for the weld strength. If the cooling time is longer than the damping time, the crystallization of the melt starts after the stopping of vibration, no crystalline structure in the weld will be destroyed. In other words, the duration of the damping time does not impact the morphology and weld strength. However, if the crystallization of the melt occurs during the damping stage, impairment of crystalline structure can be expected, resulting in a reduction of the weld strength (Fig. 2).

Literature in the field of the influence of the damping time on the weld strength produced by using vibration welding technique is sparse [14,15]. Kuriykov et al. [15] have presented that a forced shortening of the damping time can lead to an improvement in the weld strength for polyamide 66 and glass fiber reinforced polyamide 66. When the damping time was reduced from 800 to 40 ms, the weld strength of polyamide 66 increased from 40 to 65 MPa with a weld pressure of 1.5 MPa and peak amplitude of 0.7 mm. Similarly, the weld strength of 30 wt% glass fiber reinforced polyamide 66 with equal welding parameters revealed a significant enhancement by about 50% as shortening the damping time from 720 to 40 ms.

The effect of different damping time of the vibration head on the weld strength of polypropylene-based nanocomposites was investigated in this article. Furthermore, a comparison of the experimental results with those of the temperature simulations was also carried out to deeply understand the crystallization behavior during the damping time in the weld region.

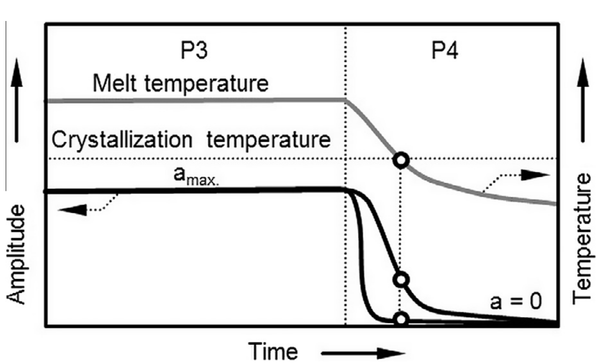

Fig. 2. Schematic representation of the time-dependent development of amplitude and temperature in phase 3 and phase 4.

2. Experimental section

2.1. Materials and sample preparation

Commercial polypropylene homo-polymer (HD120MO) was provided by Borealis group, Germany. The melt flow rate and the density of this product are 8 g/10 min (230 °C/2.16 kg) and 0.908 g/cm^3, respectively. A type of SiO_2 nanoparticles (Aerosil R8200, Evonik Industries AG, Germany) was used as nano-filler which has a primary particle diameter of about 12 nm according to the supplier's material data sheet. The compounding of polypropylene nanocomposites was performed on a co-rotating twin-screw extruder (TSK-N 030, Theysohn Extrusionstechnik GmbH, Germany) under the screw speed of 160 rpm. The diameter of the screw is 30 mm and it has an L/D (length/diameter) ratio of 40. The temperature zones were set from 190 °C near the hopper to 210 °C at the die. During the melt extrusion, the ventilation was kept on to remove trapped air in the blends. In order to obtain homogeneous nanoparticle dispersion, a two-step extrusion procedure was adopted for the compounding of the nanocomposites. Firstly, a masterbatch with a filler content of 14 vol% was compounded. In the second step, the pre-extruded compounds were mixed with different amount of polymer matrix and extruded to the designed nanocomposites with 1, 2 and 4 vol% SiO_2 contents. The polymer matrix was also extruded twice to obtain the same thermal histories as nanocomposites. Afterwards, the extruded granulates were injection-molded to the weld parts with a dimension of $50 \times 50 \times 4$ mm^3 using an Arburg Allrounder 420 C (ARBURG GmbH + Co KG, Germany) injection molding machine.

2.2. Welding experiments

Welding experiments were performed on a fully automatic vibration welding machine M-624 H/Hi (Dietzenbach, Germany). The vibration unit essentially consists of a spring mass system and an electromagnetic driver. The linear vibration of the vibration head mounted on the top area of the machine frame is based on the electromagnetic principle. The vibration is produced by two alternately energized solenoids which deflect the vibration head in the direction against the spring force. Extremely quick ramp-down of the vibration head can be also achieved by special control of the magnetic effect which enables a very short damping time about 40 ms after stopping of the vibration.

To examine the impact of the damping time of the vibration process on the weld strength the injection-molded sheets were butt-welded along the molding surface (50×4 mm^2) in the opposite of the injection gate. Table 1 shows the process parameters