Effect of strong constant magnetic field on the nanostructural organization and prop erties of the welded joints of hard-to-weld polymers (like polyethylene – polypropylene)

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Abstract

Peculiarities of nanostructural organization, thermomechanical and performance characteristics of the welded joints of hard-to-weld polymers (like polypropylene-polyethylene) formed under the effect of strong constant magnetic field (B ~1 T), as well as without such effect, were investigated by WAXS, SAXS, thermomechanical analysis and mechanical testing methods. It was determined that strong constant magnetic field causes formation of the oriented structure of the welded joint, where the axle of structurization coincides with the field axle. This effect reveals in improvement of the thermomechanical and the performance characteristics of the welded joints. Basing on the mechanical tests results it was founded that tensile strength of PE-80/PP-80 joint welded under the effect of constant magnetic field (acting transversally to the welding axle) is 12 MPa, and of welded without magnetic field effect is 6 MPa.

Keywords: *hard-to-weld joints, polyethylene, polypropylene, properties, PE-80, PP-80, structure.*

Progress in the modern material science has caused wide expansion of thermoplastics application in various industries: chemical, construction, medical, radio-technical, electronic, foodstuff etc. [1–6].

Welding process for thermoplastic polymers happens with activation of the welded surfaces either before bringing these surfaces in contact (hot tool, hot gas or IR-radiation welding) or with activation of surfaces simultaneous with bringing surfaces in contact (friction or ultrasonic welding) [7].

A number of physical and chemical transformations of polymers are occurring during the welded joint formation: melt fluidity is changing, oriented crystallization, re-crystallization, destruction, etc., takes place, and as a result non-homogeneous structure of welded joint is formed [8, 9]. Magnetic field effect is a prospective method for the improvement of the structure, as well as of physical and mechanical characteristics of joints of thermoplastics welded by the heated tool, ultrasonic and by other methods [10, 11]. It is known [12, 13] that local areas, where segments of macromolecules are parallel to each other are present in the melts of semi-crystalline polymers with flexible chains under temperatures higher than the melting temperature. Such areas have structure similar to the structure of crystalline polymers; the difference is in the lack of order in transversal and longitudinal direction. Similarly to the crystals such areas have anisotropic magnetic sensibility, and they are oriented in magnetic field in such way that carbon chains are oriented normally to the magnetic field vector.

Today there is a problem of welding of hard-to-weld thermoplastic polymers. Using the effect of constant magnetic field on the process of thermal welding of thermoplastic materials gives possibility to receive the welded joint with improved structure and better physical and mechanical properties – thanks to orientation and more tight packing of the welded joint elements. In this regard a new effective approach is proposed for the formation of the welded joints of hard-to-weld materials with ordered structure, and, respectively, for the achieving of better physical and mechanical properties under the effect of the constant magnetic field.

Thereby, the goal of this work was to investigate the structural organization, thermomechanical and operation properties of polypropylene (PP-80)/polyethylene (PE-80) welded joints received under constant magnetic field ($B \sim 1$ T) effect, and without such effect.

Methods. Materials and processing

Heated tool butt welding experiments have been carried out on model hard-to-weld couples of polymers (like polypropylene (PP-80) – polyethylene (PE-80)), with the following welding parameters: heated tool temperature 200 °C, upsetting pressure 0.2 MPa within 60 s, with dwell time 3 s and cooling time 6 min. The model objects were welded and cooled down to the ambient temperature directly under the action of magnetic field and in the absence of the field. The

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constant magnetic field was created by two neodymium magnets. The distance between them was regulated to guarantee the equality of the magnetic-field induction to 1 *T*.

Equipment and measurements

The amorphous and amorphous-crystalline structure peculiarities of PP-80 and PE-80 specimen, as well as PP-80/PE-80 welds have been investigated by wide-angle X-ray scattering (WAXS) method using DRON-4-07 diffractometer (Burevestnik, Saint Petersburg, Russia), whose X-ray optical scheme was used to "pass" primary-beam radiation through samples.

The heterogeneous structuring of these polymeric systems (at the nanometer level) was studied via small-angle X-ray scattering (SAXS) with a CRM-1 camera (Orel scientific equipment factory, Russia), having a slit collimator of the primary irradiation beam made via the Kratky method. The geometric parameters of the camera satisfied the condition of infinite height of the primary beam [14].

All X-ray structural investigations have been carried out using CuK_{α}-emission monochromated by using Ni-filter, at temperature $T = 20 \pm 2$ °C.

Thermomechanical studies of polymer systems were conducted using the penetration method in the mode of a uniaxial constant load (σ = 0.5 MPa) with UIP-70M device (central design engineering bureau of the special instrument making of the Russian Academy of Sciences). Linear heating of samples was performed at a rate of 2.5 °C/min in the temperature range 0 to +150 °C. Relative penetration (%) was calculated as:

$$\varepsilon = (\Delta l / l_0) \cdot 100,$$

where Δl is penetration (µm) at certain temperature, l_0 is initial thickness of the sample (µm).

Mechanical properties (strength and elongation at break) of initial and welded specimens have been evaluated by means of tensile axial test (according to DBN B.2.5-41 standard) with a 50 mm/min tension rate at room temperature with FP-10 tension machine (Germany). Welding quality was also estimated basing on visual geometrical parameters. All investigations were repeated three times with different specimens for each time to enhance accuracy of the measurements.

Specimens for structure and properties investigations with 1 mm thickness were cut out from the welded joints as it is shown on Fig. 1.

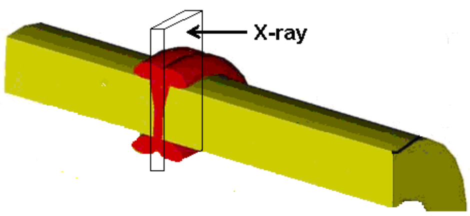

Figure 1 – Scheme of the welded joint of PP-80/PE-80 pipe types with position of a sample for X-ray study

Results and discussion

Polypropylene PP-80, polyethylene PE-80, and their welded joint's PP-80/PE-80 WAXS diffraction patterns analysis has shown that they all have amorphous-crystalline structure confirmed by respective diffraction maximums on the background of imaginary amorphous halo (Fig. 2).

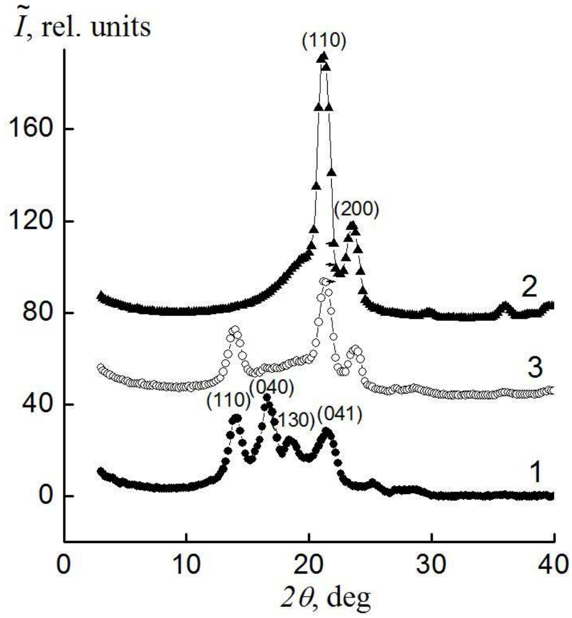

Figure 2 – WAXS diffraction patterns of polypropylene PP-80 (1), polyethylene PE-80 (2) and PP-80/PE-80 welded joint (3)

Comparing the individual PP-80 and PE-80 diffraction patterns with the pattern of PP-80/PE-80 joint one can see that during the welding of dissimilar polymers we receive the structure different to the structure of individual polymers. Diffraction maximums on the plates (040) and (130), typical to polypropylene, are absent on the diffraction pattern of the welded joint. We suppose that the crystalline phase is melted during the welding, with further re-crystallizing and simultaneous orientation of crystallites under the influence of magnetic field applied during the welding.

WAXS diffraction patterns analysis of PP-80/PE-80 welded joints received without and with magnetic field effect (Fig. 3) has shown that effect of transversal constant magnetic field on the melt of dissimilar polymers causes formation of oriented structure of welded joint, where the axle of the texture coincides with the direction of magnetic field action. This is indicated with decreasing of maximums intensity at $2\theta_{max}$ = 21.2 and 23.6°, that are featuring the structure of polyethylene component, and with increasing of diffraction maximums at $2\theta_{max}$ = 14.0, 16.8 and 18.5°, featuring the polypropylene component of the welded joint (curves 1, 2).

Formation of the welded joint under the effect of longitudinal magnetic field leads to the letdown of its physical and mechanical properties; that could be explained with counteraction of the forces applied during the welding to the magnetic field effect. This is indicated with the increase of the maximum intensity of the polypropylene component at $2\theta_{max}$ = 21.2° and decreasing of maximum intensity at $2\theta_{max}$ = 14.0°, featuring the structure of polypropylene component of the welded joint (curves 1, 3).

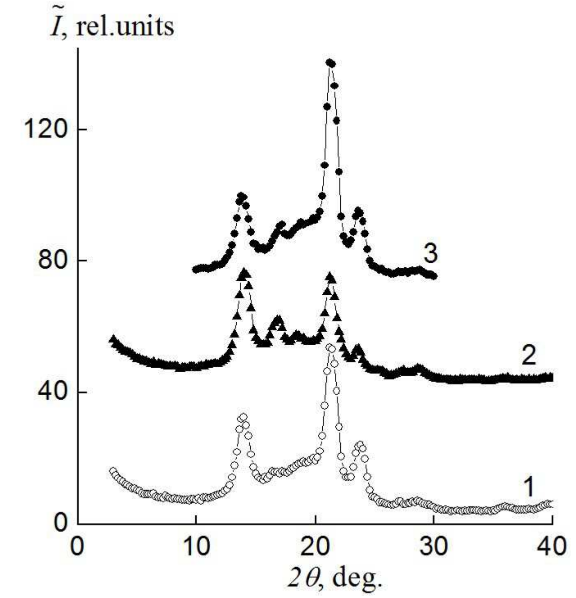

Figure 3 – WAXS diffraction patterns of the PP-80/PE-80 welded joints received without magnetic field effect (1), and under the effect of transversal (2) and longitudinal (3) magnetic field

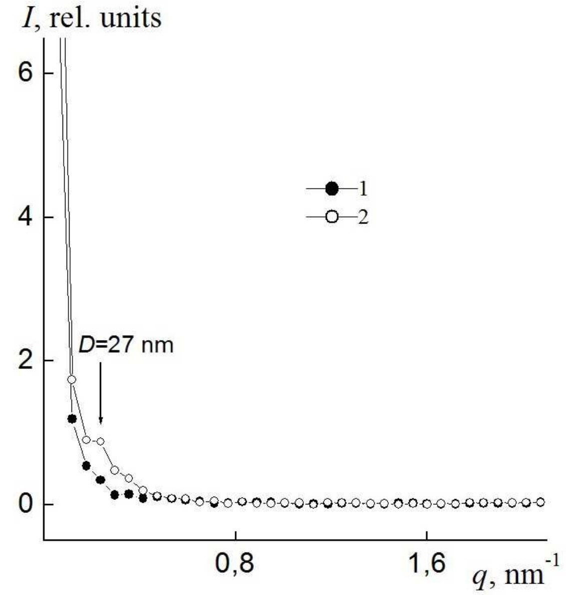

Figure 4 – Profiles of SAXS intensity of the PP-80/PE-80 welded specimens received without (1) and with (2) effect of magnetic field

SAXS diffraction patterns analysis of PP-80/PE-80 welded joints has shown increase of intensity of the diffraction maximum for the welded joint formed under the effect of magnetic field, and this is in full correlation with WAXS data, and confirms its oriented structure (Fig. 4). The average value D of the similar on the density areas of heterogeneity (distance between the nearest centers of same-type areas of heterogeneity), according to the Bragg's equation, concerning the "sinus law" for the small angles ($2\sin\theta=\sin 2\theta=2\theta$):

$$D = \lambda / 2\theta_m ,$$

For the welded joint formed under the effect of magnetic field and without such effect is ~27 nm.

Estimation of the effective size of the existing areas of heterogeneity in the volume of PP-80/PE-80 welded joints received with and without effect of the constant magnetic field has shown that under the effect of constant magnetic field much larger areas of heterogeneity are formed (l_p = 39 nm), comparing with the initial state (l_p = 31 nm).

Thermomechanical analysis of the welded joints formed with and without the effect of constant magnetic field (Fig. 5) has shown that the specimen formed under the constant magnetic field effect has not undergone any deformation, on contrary to the specimen formed without the field (curves 1, 2). Peak is detected on the welded joint's thermomechanical curve at 125 °C temperature; we guess, this can be explained by more ordered structure of the welded joint (i. e. by lower ability to be pressed through) comparing to one received without magnetic field effect.

According to the results of uniaxial tensile tests it was determined that tensile strength of a PP-80/PE-80 welded joint received under the effect of constant magnetic field transversal to the upset direction was 12 MPa, and of a specimen received without magnetic field effect was 6 MPa.

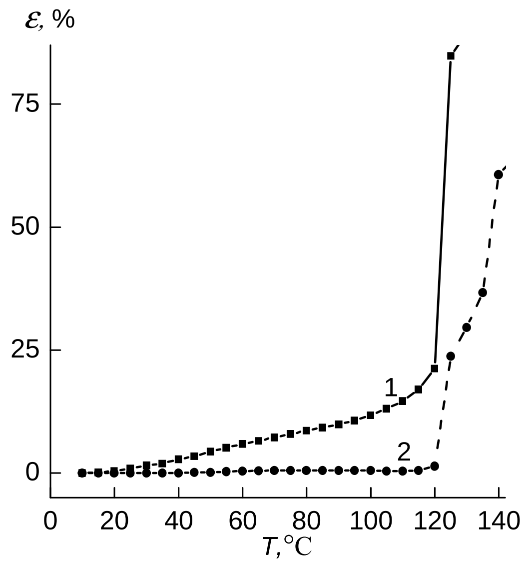

Figure 5 – Thermomechanical curves of the PP-80/PE-80 welded joints received without (1) and with effect of the transversal magnetic field (2)

Conclusions

Structure, thermomechanical and performance characteristics of hard-to-weld pairs of polymers (like PP-80/PE-80) welded with and without effect of strong constant magnetic field were investigated. It was shown that strong constant magnetic field effect on the melts in the welded area causes formation of the oriented welded structure, where the structure axle coincides with the magnetic field axle. This effect reveals in the improvement of thermomechanical and performance characteristics of the welded joints; this can be explained by magnetically-anisotropic orientation of macromolecules and aggregates (present in the melt) in the magnetic field.

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Вплив сильного постійного магнітного поля на наноструктурну організацію і властивості важкозварюваних полімерів (поліетилен – поліпропілен)

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Методами широко- та малокутового розсіювання рентгенівських променів, термомеханічного аналізу та механічних випробувань досліджено особливості наноструктурної організації, термомеханічні та експлуатаційні характеристики зварних з'єднань із важкозварюваних полімерів типу поліпропілен–поліетилен, сформованих під дією сильного магнітного поля (В ~ 1 Т) та за його відсутності. Встановлено, що дія постійного магнітного поля на формування зварного з'єднання у процесі теплового зварювання приводить до виникнення орієнтованої структури зварного з'єднання, вісь текстури якого збігається з напрямком дії магнітного поля. Це проявляється в поліпшенні термомеханічних та експлуатаційних характеристик отриманих зварних з'єднань. На підставі результатів механічних випробувань встановлено, що розривна міцність зварних з'єднань ПЕ-80/ПП-80, сформованих під дією поперечного постійного магнітного поля, становить 12 МПа, а сформованих без впливу магнітного поля – 6 МПа.

Ключові слова: *важкозварюване з'єднання, властивості, поліетилен, поліпропілен, ПЕ-80, ПП-80, структура*.