Kovove Mater. 51 2013 63–70
DOI: 10.4149/km_2013_1_63

Vibration welding of high density polyethylene HDPE – purpose, application, welding technology and quality of joints

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Received 23 September 2011, received in revised form 13 June 2012, accepted 24 September 2012

Abstract

The article describes the problems of vibration welding as an alternative method of joining thermoplastics. This technology makes possible to join polymers in only several seconds. This method can be successfully applied for joining of wood as well. The process of polymers joining has been described in details using the example high density polyethylene which is one of the most commonly used thermoplastics. Examination of welded joints has been presented. The authors focused on the macro- and microscopic examinations which make possible to examine the structure of vibration welded joints in polyethylene HDPE (high density polyethylene). The examples of micro- and macrostructures have been shown.

Key words: thermoplastics, high density polyethylene, HDPE, vibration welding

1. Introduction

Over the past few years the rapid development of industrial application of thermoplastics has been noticed. Polymer materials begin to play a part of great importance in various industrial branches. Domination of plastics is especially noticeable in the time of economic crisis which influenced worldwide economy when the activities connected with recycling of materials such as cellulose, light metals or glass faced the threat of bankruptcy.

The statistics show that in packaging industry products made of plastics make up 20–25 % of the whole production [1]. Automotive industry is the branch where structural components made of plastics are especially easy to notice. About 12 % of materials used in car production are composites and polymer materials [1]. These materials are used in production of components such as bumpers, seats, upholstery, control panels, components of fuel systems, headlights, outside stripes and other components of car body, etc.

Thanks to low costs and flexibility in making of various components plastics are nowadays very competitive structural materials in the comparison to those of steel and non ferrous metals.

Thermoplastics play the main role among polymer materials with industrial applications. On the other hand among thermoplastics one of the most commonly applied is polyethylene (PE), world consumption of which grows very quickly year by year [1].

Thermoplastics can be joined using various methods such as hot plate welding, extrusion or hot air welding, electric resistance welding or bonding, etc. By reason of the dynamic growth of plastics consumption, nowadays innovation technology of their joining which could be applied to produce permanent joints of the best, especially mechanical, properties in a short time are being investigated.

One of the most inventive methods of joining of plastics is vibration welding. It is an alternative to traditional methods of plastics joining, such as hot plate or extrusion welding. The competitiveness of vibration welding emerges mainly in the time of duration of the joining process and user-friendliness of the welding equipment.

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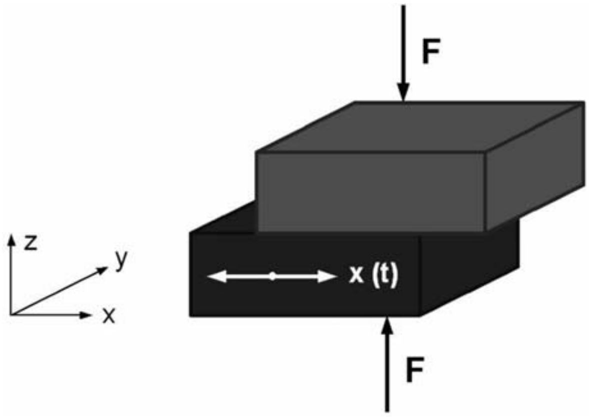

Fig. 1. The principle of vibration welding process [2].

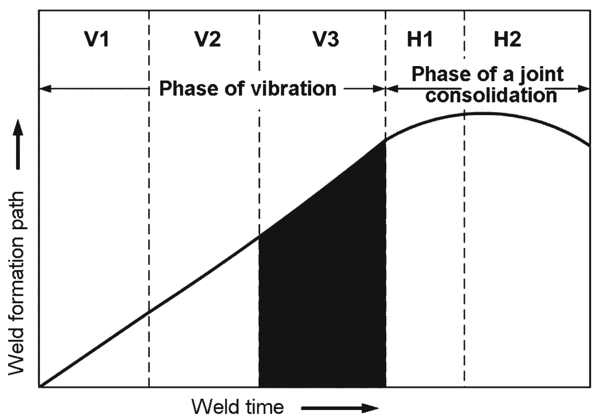

Fig. 2. Phases of vibration welding process [2].

2. Characteristics of vibration welding process

Vibration welding is a variant of the friction welding. It makes possible to obtain a permanent joint in a short time. Vibration welding can be applied for joining metallic and polymer materials as well as wood. Using vibration welding it is possible to join dissimilar polymer materials providing the materials have the same crystalline structure. Unquestionable advantage of vibration welding is the possibility of joining materials which are difficult or even impossible to join using other welding technologies, e.g. wood. During vibration welding there is no emission of harmful substances to the environment and therefore the process is environment friendly.

The principle of vibration welding process is shown in Fig. 1.

While vibration welding process for one component to be joined is constrained in the fixture of welding unit, the other welded part undergoes reciprocating motion. The movement can be linear, oscillatory or biaxial. Prior to the process, such welding parameters as: weld force, weld time, vibration amplitude and parts shrinkage are being set. The adequate module of welding is also selected. The accurate preparation and cleaning of the surfaces to be welded are very important stages in the welding process. When the process is begun (start of vibration), after several seconds the material of the components is plasticised. In the literature several phases of vibration welding process are described, which are shown in Fig. 2.

Phase V1 is a phase when components are heated up to the plasticising temperature thanks to heat generated by the friction of two surfaces of parts to be joined. Phase V2 is the beginning of the creation of the thin layer of plasticised thermoplastic material on the surfaces of components. As time goes on the process intensifies. In the phase V3 plasticised thermoplastic material is being put into the state close to the state of energy equilibrium. In this phase the components are brought closer due to the impact of applied weld force and the flash occurs [2].

3. Quality of vibration welded joints in thermoplastics

Welded joints produced using vibration welding process have good tensile strength, usually higher than that of parent material as well as high leak proofness.

Quality assessment of vibration welded joints is conducted based on the requirements of standards devoted to standard methods of joining thermoplastics, e.g. PN-EN 13100-1 [3], PN-EN 12814-5 [4], PN-EN 14728 [5]. This evaluation is conducted after both non-destructive and destructive testing. Tests to be conducted include such trials as: visual inspection, tensile and bend testing of joints. It should be emphasised that there are no direct assessment criteria for joints made in plastics produced using vibration welding process [2, 6, 7].

4. Material and equipment used during research

Quality of joints in thermoplastics is affected by following properties of the material: polymer structure, thermal capacity, modulus of volume elasticity, coefficient of friction and softening point. During welding of dissimilar thermoplastics the production of a good joint is determined by the structures of welded materials. Research has revealed that it is possible to join thermoplastics of the same structure, i.e. polymers of semi-crystalline structure with the polymer of semi-crystalline structure as well as amorphous polymers with amorphous polymers.

During research high density polyethylene HDPE

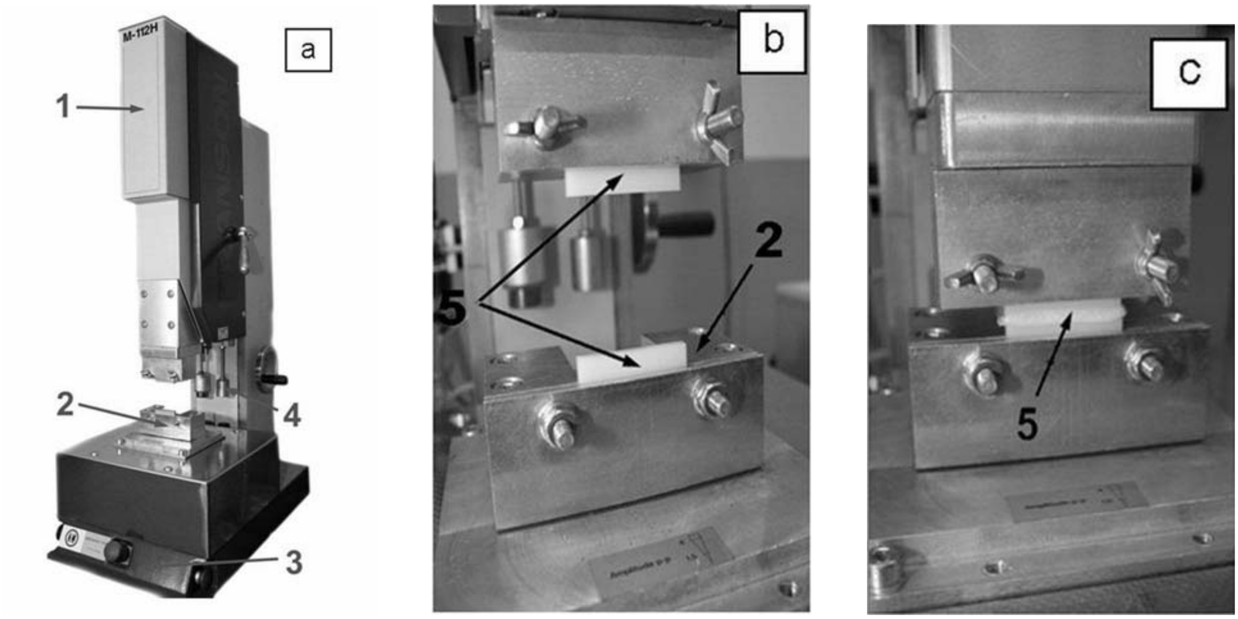

Fig. 3. Vibration welding station: a) general view: 1 – upper tooling moving unit, 2 – vibration head with lower tooling, 3 – control desk, 4 – control system, b) view before welding process: 2 – vibration head with lower tooling, 5 – components to be joined, c) view of the machine after the welding process: 5 – produced joint.

T a b l e 1. Vibration welding parameters of selected joints in HDPE polyethylene

No of joint	Pressure (bar)	Clamp force (daN)	Set parameters: Weld depth (mm)	Set parameters: Vibration amplitude (mm)	Set parameters: Weld time (s)	Real parameters: Weld depth (mm)	Real parameters: Vibration amplitude (mm)	Real parameters: Weld time (s)
2				1.4	–	1.47	1.51	4.18
3	4	168	1.2	1.5	–	1.39	1.58	3.93
4				1.6	–	1.43	1.56	3.81

was used. The trials of vibration welding of thermoplastics were conducted at Instytut Spawalnictwa in Gliwice using the vibration welding machine equipped with Branson M112H control system. The welding station is shown in Fig. 3. Testing station has been equipped in computer program that makes possible to record welding parameters.

Two sensors are placed on the welding machine body: safety sensor and travel sensor which is used to measure the depth of penetration. Moreover, the Branson M112H vibration welding machine is equipped with electric circuits which generate voltage proportionally to the vibration amplitude, weld displacement and force of fixtures clamping components to be joined.

Research results obtained during testing have been recorded on the selected storage carrier (portable discs, flash memory, CD) so as to be able to be processed using processing programs, e.g. Statistica or Excel spreadsheet.

The welding machine can perform welding process

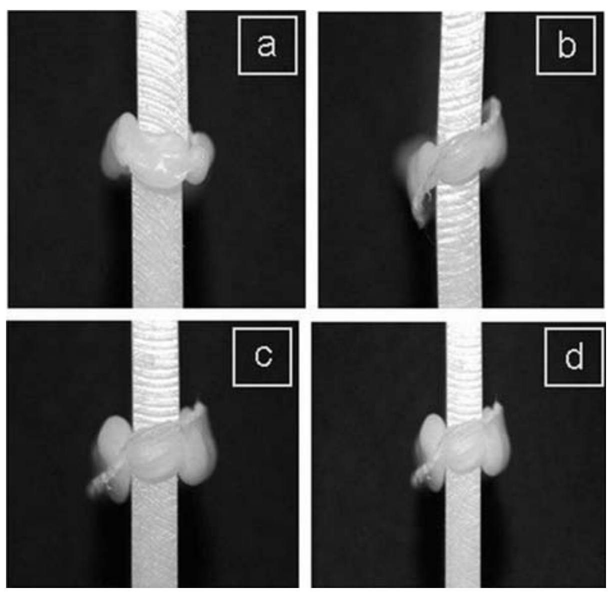

Fig. 4a–d. General view of vibration welded joints in polyethylene HDPE.

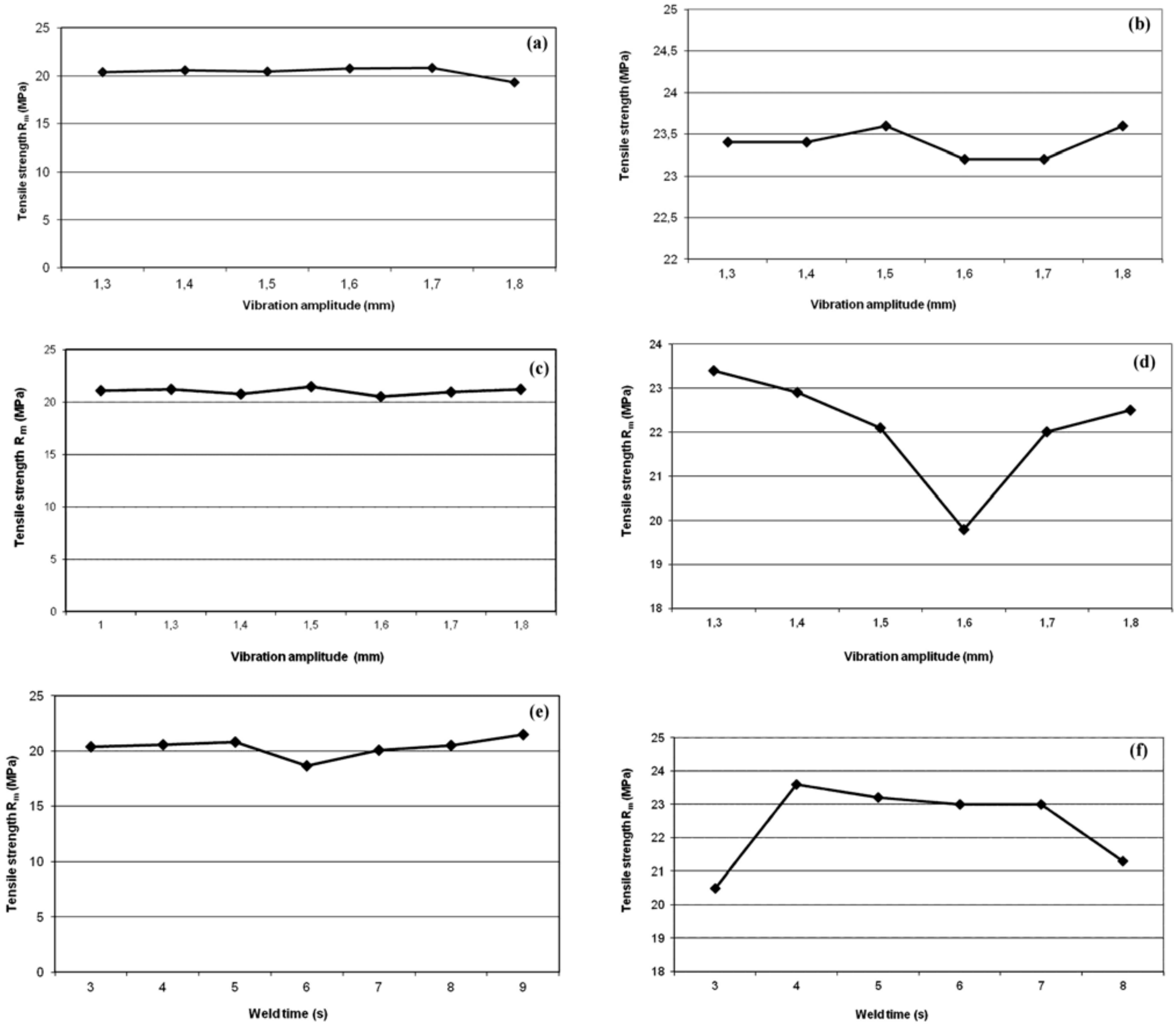

Fig. 5. The results of tensile strength testing of vibration welded joints in HDPE polyethylene. The relation of tensile strength R_{m} to: a) vibration amplitude for weld mode of relative depth. Surface preparation: turning; b) vibration amplitude for weld mode of relative depth. Surface preparation: rough; c) vibration amplitude for weld mode of time. Surface preparation: turning; d) vibration amplitude for weld mode of time. Surface preparation: rough; e) vibration time for weld mode of time. Surface preparation: turning; f) vibration time for weld mode of time. Surface preparation: rough.

in three ways:

1. *relative depth* – the mode that makes possible to produce a joint of specified relative shrinkage,

2. *absolute depth* – the mode where the shrinkage of a component is also set but parts are joined with a certain dimensional tolerance. If components to be joined are shorter the depth of penetration will be smaller. For longer parts the welding process may be disturbed,

3. *time* – the mode in which time of the process duration is the parameter to be set.

In industrial conditions the "relative depth" process is the most often applied due to the dimensional deviations of the components which occur frequently.

5. Course of research and results

The area of research into high density polyethylene HDPE included following activities:

a) vibration welding testing,

b) tensile testing of welded joints,

c) structural testing of welded joints.

In order to test vibration welding process samples of (length × width × thickness) $60 \times 50 \times 5\ \mathrm{mm}^3$ were prepared. The surface of the samples to be joined was prepared in two ways: roughly or by turning. In order to ensure adequate cleanness the joined surface was cleaned with alcohol just before the welding process. During welding process following parameters were re-

T a b l e 2. Procedure for preparation of samples of HDPE polyethylene for microscopic examination

Stage	1	2	3	4	5
Abrasive	SiC-Paper #500	SiC-Paper #1200	SiC-Paper #2400	MD-Dac	MD-Chem
Abrasive disk revolution (rpm)	300	150	150	150	150
Abrasive material	–	–	–	DiaPro Dac	OP-S, 0.04 μm
Lubricant	water	water	water	–	–
Clamping force (N)	25/150	25/150	25/150	25/150	10/60
Sense of rotation	>>	>>	>>	>>	>>
Fixture rotation (rpm)	150	150	150	150	150
Time (s)	up to the surface smoothing	30	45	300	120

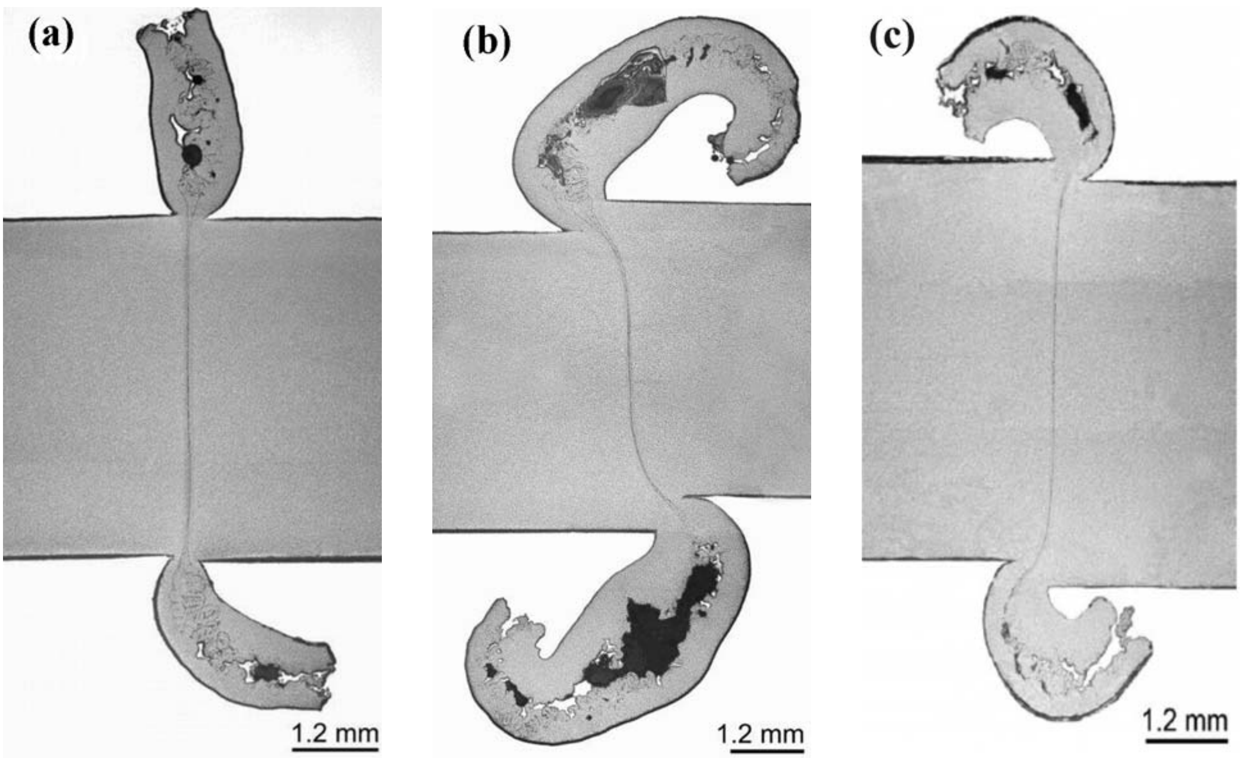

Fig. 6a,b,c. General view of cross-section of joint in HDPE polyethylene for various parameters of the vibration welding process.

corded: vibration amplitude, weld time as well as relative shrinkage of the joint. The parameters of welding process for selected joints are shown in Table 1.

After welding, visual examination of welded joints was conducted, which included the estimation of flash geometry and its position relative to the joint axis. The selected samples of welded joints in polyethylene HDPE are shown in Fig. 4.

In vibration welded joints produced in polyethylene HDPE for high vibration amplitudes the weld flashes are large. Moreover, they are empty inside and have characteristic shape.

Tensile strength testing of joints in thermoplastics was conducted in accordance with the requirements of PN-EN 12814-2 standards [7] using tensile strength testing machine of measuring range 2000 daN. Selected examples of the results of tensile strength testing of vibration welded joints are shown in Fig. 5.

As a result of tensile testing it has been noticed that:

1. irrespective of the welded polymer type in the case of the surface preparation by turning the tensile strength of the joint is in the repeatable level,

2. rough preparation of the surface to be joined causes diversity of strength results of tested joints as well as joints quality is not repeatable,

3. tensile strength of joints in HDPE polymers with surfaces prepared by turning is practically at a constant level, irrespective of welding parameters and welding mode (Fig. 5a,c,e).

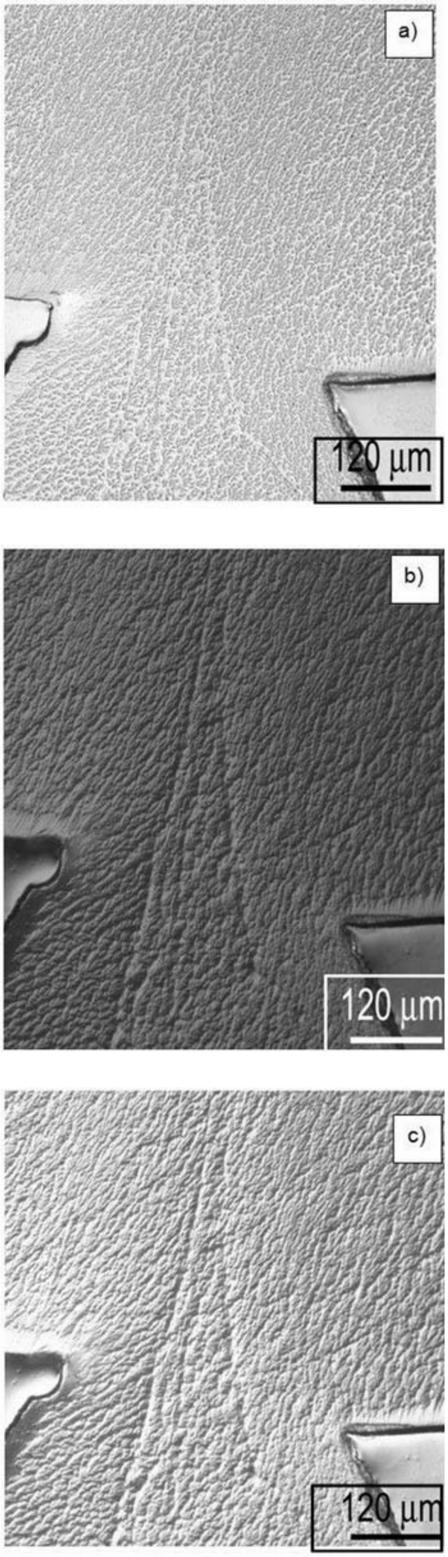

Fig. 7. The details of the structure in the area of the flash transition into the joint in HDPE polyethylene (joint No. 2) depending on the observation mode in the optical microscopy: a) observation in the light field, b) observation using differential interference contrast DIC, c) observation using differential interference contrast DIC and yellow filter.

In the next part of research structural tests were conducted for the vibration welded joints in high dense polyethylene HDPE which consisted of microscopic visual inspection in the reflected light using optical MeF4M Leica type microscopy for various observation modes.

Very precise preparation of the surface of the metallographic specimen is the necessary condition for good and effective final result of microscopic testing of plastics. In the subsequent part of this study the results of microscopic examination of HDPE polyethylene has been shown in the form of microstructures, therefore in Table 2 the detailed procedure of preparation of samples for structural testing is presented. The procedure was applied at the Laboratory of Metallographic Testing of Instytut Spawalnictwa in Gliwice.

Parts of vibration welded joints for microscopic examination were cold mounted using Struers Epofix resin. Samples were prepared using materials of Struers company and Buehler PowerPro 4000 grinding and polishing machine. Preparation procedure included grinding of the surfaces of metallographic specimens with abrasive papers of various gradations (3 stages) and two-stages polishing (Table 2).

The selected examples of structural examination results are shown in Figs. 6 and 7.

The microstructures in Fig. 7 show that the best details of the topography of welded joints in plastics can be revealed using differential interference contrast DIC and yellow filter during microscopic observations. This mode was used during further research.

Microscopic examination has shown that depending on the change of the vibration welding parameters the character of the joints is changing in the various joints areas. The examples of the alterations occurring in the welded joint are shown in Fig. 8.

6. Summary

In the vibration welded joints in HDPE polyethylene the flash is of large dimensions and is empty inside what has been confirmed in the macroscopic examination (Fig. 6). Size and shape of the flash depend mainly on vibration amplitude and time of welding process duration. The higher vibration amplitude and the longer weld time the greater the flash size is. The examination of macrostructures of welded joints (Fig. 6) has showed that the structure is uniform and without visible defects and imperfections. In case of joint No. 3 which was produced using the highest amplitude tested the linear misalignment (lack of coaxiality) between welded pieces can be observed, but it does not reduce the joint quality. In general, the joint line that is visible in a cross-section changes its characteristic from rectilinear to curvilinear with increas-

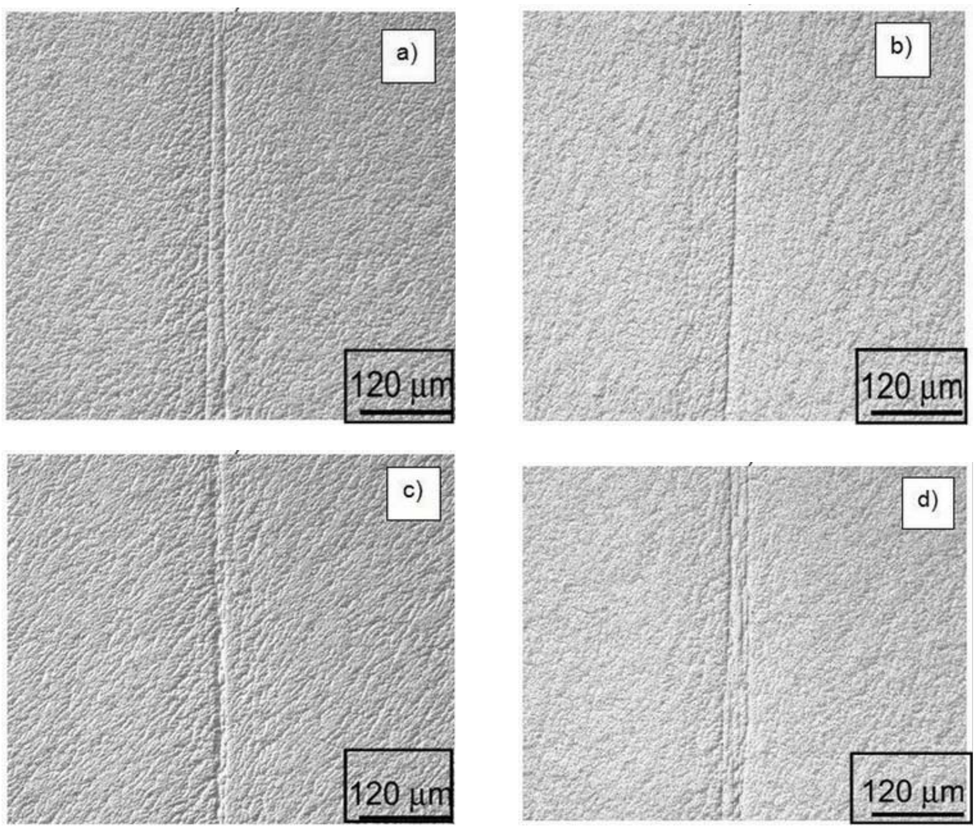

Fig. 8. Changes in the morphology of a vibration welded joint in HDPE polyethylene depending on welding parameters of the process and area of the observation: a) joint No. 2, area near the flash, bifurcated joint line, b) joint No. 4, area near the flash, compact joint line, c) joint No. 2, area in the half-thickness of a joint, compact joint line, d) joint No. 4, area in the half-thickness of a joint, bifurcated joint line.

ing vibration amplitude during vibration welding process.

During microscopic observation of tested joints crucial from the quality viewpoint weld areas – from the flash and area of transition between flash and weld to central part of a joint (half-thickness of a joint) – was analysed. It has been noticed that the character of the weld line undergoes serious changes depending on the welding parameters, especially vibration amplitude. For lower vibration amplitude (joint No. 2) in the area of transition between flash and weld the weld line is bifurcated (Fig. 8a). On the other hand in the central part of the joint the weld line becomes uniform and compact (Fig. 8c). For the higher vibration amplitude (joint No. 4) the weld line morphology and the character of its alteration is opposite (Fig. 8b,d). In the flash area of welded joint plasticised plastic material pushed outside under the pressure creates characteristic delta shape (Fig. 7).

Based on the mechanical testing results it can be observed that irrespective of vibration welding parameters the tensile strength of the tested joints is similar and higher than that of parent material.

7. Conclusions

Following conclusions can be drawn from conducted research:

1. In order to obtain the repeatable and high quality joints in high density polyethylene HDPE the surfaces of joined parts should be prepared very carefully by e.g. turning.
2. Correct preparation and adequate operating materials make possible to produce good quality metallographic specimens of HDPE polyethylene for microscopic examination.
3. Vibration welding process proved to be useful and effective for production of joints in high density polyethylene HDPE.
4. The detailed estimation of the impact of separate parameters of vibration welding process on the shape and morphology of HDPE joints requires the continuation of structural examination.

Acknowledgements

This article was written based on the statutory research project of Instytut Spawalnictwa in Gliwice entitled Investigation into the friction welding conditions of unwelded and difficult to weld structural materials No. ST-254/Bb-103, 2008. The authors wish to thank Mr. Grzegorz Uszyński from STRUERS for technical help.

References

[1] Jasiulek, P.: Combining plastic welding methods, welding, gluing and laminating. Krosno, Wydawnictwo KaBe 2004.

[2] PN-EN 13100-1:2002 Non destructive testing of welded joints of thermoplastics semi-finished products. Part 1: Visual examination.

[3] PN-EN 12814-5:2002 Testing of welded joints of thermoplastics semi-finished products. Part 5: Macroscopic examination.

[4] PN-EN 14728:2006 Imperfections in thermoplastics welds. Classification.

[5] Pusz, A.: Joining plastics. Seminar Materials. Gliwice, Welding Institute in Gliwice 1994.

[6] Węglowska, A.: Welding, plastics – combining modern technology, research connections, news standards. Seminar Materials. Gliwice, Welding Institute in Gliwice 2006.

[7] PN-EN 12814-2:2002 Testing of welded joints of thermoplastics semi-finished products. Part 2: Tensile test.

[8] Kunststoffe 10/2002.