These requirements may be satisfied with the subject matters of the independent claims. Advantageous embodiments are explained in the dependent claims, the following description and the enclosed figures.

A first aspect of the invention relates to an ultrasonic welding device according to claim 1. The ultrasonic welding device comprises at least one sonotrode and a sonotrode carrier which is formed to cause ultrasonic vibrations of the sonotrode. The sonotrode and the sonotrode carrier have in each case a contact face, also referred to below as a coupling face. At least one of the contact faces is roughened at least in sections. The sonotrode is fastened exchangeably to the sonotrode carrier in such a manner that the contact faces are pushed against one another.

A second aspect of the invention relates to a method according to claim 8 for producing a sonotrode for an ultrasonic welding device, as is described above and below. The method comprises at least one step of providing the sonotrode in a state to be processed and a step for processing the sonotrode in order to roughen the contact face of the sonotrode at least in sections.

A third aspect of the invention relates to a method according to claim 9 for producing a sonotrode carrier for an ultrasonic welding device, as is described above and below. The method comprises at least one step of providing the sonotrode carrier in a state to be processed and a step of processing the sonotrode carrier in order to roughen the contact face of the sonotrode carrier at least in sections.

It should be pointed out that features of the ultrasonic welding device may also be understood as features of the methods described above and below and vice versa.

Without restricting the scope of the invention in any manner, embodiments of the invention may be regarded as being based on the concepts and findings described below.

As already mentioned, the connection between the sonotrode and the sonotrode carrier is decisive for the quality of the welding result. How good this connection is may depend on various influencing factors, for example, on whether the specified tightening torque of the screw(s) is adhered to, how clean the contact faces are, or on the production-specific surface properties of the contact faces.

The approach presented here thus makes it possible to make the connection between the sonotrode and the sonotrode carrier significantly less sensitive to contamination, for example, by oil or grease, to errors in the maintenance and mounting of the sonotrode and to

fluctuations in the production of the relevant components, and indeed without undesirable notches being generated on the sonotrode and/or the sonotrode carrier. Such notches may, even if they are relatively small, given the high level of strain to which the sonotrode or the sonotrode carrier is exposed during welding operation, potentially lead to damage.

This is in principle achieved in that the friction between the sonotrode and the sonotrode carrier is increased by targeted roughening of one or both contact faces, or at least one section thereof, in a suitable manner. In other words, by corresponding roughening of the sonotrode and/or the sonotrode carrier using a suitable processing method, one or more roughened sections may be created within one or both contact faces which may hook together at the microscopic level with the corresponding counterpart, for example, one or more sections which have not been roughened and/or one or more sections of the counterpart which have also been correspondingly roughened. Such a micro-toothing ensures, during welding operation, a reliable connection between the sonotrode and the sonotrode carrier, and indeed without the clamping force with which the sonotrode and the sonotrode carrier are pushed against one another having to be increased.

It was possible to demonstrate this advantageous effect in tests in which a rotational force was measured which is required to rotate a sonotrode in the form of what is known as a flexural resonator (see further below) with respect to the sonotrode carrier.

The following parameters were used for the tests: Distance of the force application point for the rotational force from the center of the sonotrode: 78 mm; feed: 2 mm/min; tightening torque of the screws for fastening the sonotrode to the sonotrode carrier: 20 Nm. The introduction of force was performed perpendicular to the longitudinal axis of the sonotrode.

In this case, it was possible to increase the rotational force from approx. 550 N for a sonotrode with an unprocessed, i.e. not specially roughened contact face to approx. 800 N for a sonotrode with a contact face roughened by laser processing and even to l150 N for a sonotrode with a contact face roughened by blasting with glass pearls. It was therefore possible to more than double the stability of the fastening while having the same tightening torque. All of the tested sonotrodes were unremarkable in terms of vibration characteristics.

The increase in the rotational force may be explained by virtue of the fact that, as a result of a defined structure within the contact face on the sonotrode and/or on the sonotrode carrier, a type of positive locking on a microscopic scale, i.e. a micro-toothing, is generated. The structure may be embodied so that it minimally penetrates into the corresponding counterpart, i.e. that the sonotrode and the sonotrode carrier do not touch at the contact face in a punctiform or linear manner, but rather in a superficial manner. The structure used for

the micro-toothing and/or a surface, pressed together with the structure, of the counterpart may be slightly elastically and/or plastically deformed. Projecting edges or peaks of the structure generated by the roughening may penetrate slightly into material, which is close to the surface, of the counterpart and thus bring about the micro-toothing. The deformations may be only a few millimeters or even smaller, in particular significantly smaller than the structure generated by the roughening.

Some of the terms used above and below are explained in greater detail below.

The term contact face may be understood on one hand as a macroscopically flat surface section of the sonotrode on which the sonotrode has contact with the contact face of the sonotrode carrier. On the other hand, this may be understood as a macroscopically flat surface section of the sonotrode carrier on which the sonotrode carrier has contact with the contact face of the sonotrode. The two contact faces may be brought to cover one another by fastening the sonotrode to the sonotrode carrier and be pushed against one another with a defined clamping force.

It is possible that the sonotrode and the sonotrode carrier touch exclusively at their contact faces.

The contact face may be roughened in sections, i.e. in one or more coherent or separate sections. Alternatively, the entire contact face may be roughened, i.e. the roughened section may extend over the entire contact face.

The term roughened section may be understood in this context as a specially processed, for example, flat section of the contact face which, as a result of the special processing, has a significantly greater roughness than a section of the contact face which has not been processed in such a manner or another surface of the sonotrode and/or the sonotrode carrier. For this purpose, the contact face may, for example, have been processed using a mechanical, optical, electrical (e.g. erosion), electrochemical or chemical method for surface treatment or using at least two of these methods in combination. In other words, a special friction-increasing structure may be formed in the region of the contact face by the processing, wherein the friction-increasing properties of the structure may be the same in all directions, i.e. non-directed or isotropic, or different in different directions, i.e. directed or anisotropic.

The roughness of such a roughened section of the contact face may differ quantitatively and/or qualitatively from the roughness of a section of the contact face which is not roughened in such a manner. The section which has not been roughened may be substantially

smooth, wherein any microscopic unevennesses on the surface of this section may be caused by a production or processing method. For example, the non-roughened section may have a residual roughness which originates from machining of the relevant component and/or from grinding, sanding or polishing the relevant component. Such a residual roughness is generally anisotropic, i.e. the relevant section generally has a surface structure with a preferred direction which may correspond, for example, to a processing direction during machining, grinding, sanding or polishing. The roughness of the deliberately roughened section of the contact face may be significantly greater in comparison with the non-roughened section, for example, by a factor of 2, 5 or even 10. Moreover, techniques which generate an isotropic rough surface structure, i.e. without a preferred direction, such as, for example, laser irradiation, particle blasting, in particular glass ball blasting or sand blasting may be used for targeted roughening of the contact face.

The sonotrode carrier may comprise, for example, a converter and/or a booster. The sonotrode carrier may additionally comprise a generator. The sonotrode may be fastened to a free end of the (longitudinal) sonotrode carrier, for example, of the booster or the converter, in particular in such a manner that a vibration axis, along which the sonotrode carrier may be moved to and fro with frequencies in the ultrasonic range, stands perpendicular to the contact faces.

In specific embodiments, the sonotrode carrier may additionally comprise an intermediate piece which may be fastened on one hand to the booster or converter and to which on the other hand the sonotrode may be fastened.

The term converter may be understood as an electromechanical component which is formed to convert a high-frequency electric voltage provided by the generator into mechanical ultrasonic vibrations with a corresponding frequency in the ultrasonic range, for example, between 20 kHz and 100 kHz, preferably between 20 kHz and 35 kHz.

The booster, also referred to as a transmission or amplitude transformation piece, may be formed to change the ultrasonic vibrations provided by the converter in terms of their amplitude, i.e. reduce and/or increase the amplitude, and transmit the ultrasonic vibrations changed in such a manner to the sonotrode. The booster may additionally be formed to mount the sonotrode carrier in the ultrasonic welding device.

The term sonotrode may be understood as a tool which may be caused to perform correspondingly high-frequency resonance vibrations as a result of the introduction of ultrasonic vibrations and is formed to transmit these vibrations to one or more workpieces to be welded. For example, the sonotrode, in particular if it is embodied as a two-armed

flexural resonator (see further below), may be formed to be symmetrical in relation to its longitudinal and/or transverse axis. Uneven strain on the sonotrode may thus be avoided.

According to one embodiment, the sonotrode may be fastened exchangeably to the sonotrode carrier via at least one screw. In this case, the screw may push the contact faces against one another. This enables a controlled pressing together of the contact faces. The replacement of the sonotrode may thus furthermore be simplified. The sonotrode may also be fastened exchangeably to the sonotrode carrier via two or more than two screws.

According to one embodiment, the screw may be introduced into a sonotrode opening in the sonotrode and the sonotrode opening may be surrounded at least partially by the contact face of the sonotrode. Additionally or alternatively, the screw may be introduced into a sonotrode carrier opening in the sonotrode carrier and the sonotrode carrier opening may be surrounded at least partially by the contact face of the sonotrode carrier. In other words, the screw may go transversely, in particular perpendicularly, through one or both contact faces. The frictional connection between the two contact faces may thus be improved.

According to one embodiment, the sonotrode opening may be surrounded in a ring-shaped and/or ring segment-shaped manner by the contact face of the sonotrode. Additionally or alternatively, the sonotrode carrier opening may be surrounded in a ring-shaped and/or ring segment-shaped manner by the contact face of the sonotrode carrier. This may simplify the orientation of the sonotrode with respect to the sonotrode carrier, in particular if the sonotrode is fastened to the sonotrode carrier via only one screw.

According to one embodiment, the sonotrode opening may be surrounded by at least one ring-shaped and/or ring segment-shaped roughened section of the contact face of the sonotrode. Additionally or alternatively, the sonotrode carrier opening may be surrounded by at least one ring-shaped and/or ring segment-shaped roughened section of the contact face of the sonotrode carrier. An unintentional rotation of the sonotrode relative to the sonotrode carrier during welding operation may be effectively avoided, in particular if the sonotrode is fastened to the sonotrode carrier via only one screw.

According to one embodiment, at least one of the contact faces may comprise a striped pattern composed of several stripe-shaped roughened sections. The stripe-shaped sections may be oriented in the same direction or in different directions. It is expedient if the stripe-shaped sections are distributed over the entire contact face, in particularly are evenly distributed. The striped pattern may be generated, for example, by laser processing of the sonotrode or the sonotrode carrier. It was possible to achieve particularly good results in tests with this embodiment.

According to one embodiment, the roughened sections of the striped pattern may be arranged parallel to one another. In this case, the roughened sections of the same contact face or different contact faces may be arranged parallel to one another. Each roughened section of the striped pattern may additionally run parallel to the longitudinal direction of the sonotrode. It was also possible to achieve particularly good results in tests with this embodiment.

A roughened section of the contact face which is roughened at least in sections has a roughness which is characterized in that an mean roughness depth R_z of the roughened section is greater than 2,0 µm and/or an arithmetical mean roughness value R_a of the roughened section is greater than 0.3 µm. Such lower thresholds have been shown to be particularly practical in tests.

The mean roughness depth R_z is smaller than 14 µm. Additionally or alternatively, the arithmetical mean roughness value R_a is smaller than 3.0 µm. Such upper thresholds have been shown to be particularly practical in tests.

For example, the following roughness values were measured in tests:

- for a section of the contact face roughened by blasting with glass pearls: 0.53 µm for R_a; 3.29 µm for R_z;
- for a section of the contact face roughened by laser treatment: 2.43 µm for R_a; 13.27 µm for R_z;
- for an unroughened, i.e. untreated or only polished section of the contact face: 0.16 µm for R_a; 0.90 µm for R_z.

The sonotrode is embodied as a flexural resonator which comprises a base body and at least one bending arm which projects from the base body. The sonotrode may be fastened exchangeably to the sonotrode carrier via the base body and the base body may comprise the contact face of the sonotrode. This has the effect that the sonotrode is excited to perform transversal vibrations, i.e. is elastically deformed in a wavy line shape in the vibrating state. In this case, the sonotrode may have several points, also referred to as zero crossings, at which their deflection relative to an imaginary zero line is zero or negligibly small. This embodiment makes it possible to weld even workpieces which are difficult to access.

It is possible that the base body represents the widest part of the sonotrode, while the bending arm may at least in sections be embodied to be significantly narrower and/or thinner than the base body. A sonotrode in the form of a rod-shaped flexural resonator is also possible. For example, the cross-section of the bending arm may taper with increasing distance from the base body. A free end of the bending arm may thus also be moved towards

workpieces which are difficult to access without the strength of the bending arm being significantly impaired. So that the bending arm may vibrate freely, it should not touch the sonotrode carrier. In other words, it is possible that the sonotrode touches the sonotrode carrier in the vibrating state, i.e. during welding operation, exclusively with its base body. During welding operation, the bending arm may touch a workpiece to be welded only with its free end.

For example, the flexural resonator may comprise two bending arms which project from the base body in opposite directions to one another.

According to one embodiment, the processing of the contact face of the sonotrode and/or the sonotrode carrier may comprise a laser treatment, mechanical processing by blasting with a blasting agent or a combination of the two. The processing of the sonotrode or of the sonotrode carrier may thus be performed particularly precisely. By means of a laser treatment, the relevant contact face may, for example, be melted in a punctiform manner at several points with laser pulses. Microscopically small elevations may be formed in this case at the relevant points as a function of the selected laser parameters, which small elevations have the action of a micro-toothing. For example, by means of a laser treatment, a precise striped pattern composed of several stripe-shaped roughened sections may be generated (see further above). Ring-shaped and/or ring segment-shaped patterns are, however, also conceivable, for example, patterns composed of several concentric rings and/or concentric ring segments. For example, glass pearls or sand are suitable as blasting agents. Other blasting agents are also possible.

It should also be pointed out that possible features and advantages of embodiments of the invention are explained above and below partially with reference to an ultrasonic welding device, partially with reference to a method for producing a correspondingly adapted sonotrode of the ultrasonic welding device and partially with reference to a method for producing a correspondingly adapted sonotrode carrier of the ultrasonic welding device. A person skilled in the art will recognize that the features described for the individual embodiments may, in an analogous and suitable manner, be transferred and/or adjusted to other embodiments and/or be exchanged in order to arrive at further embodiments of the invention and possibly synergistic effects.

Brief description of the drawings

Advantageous embodiments of the invention are explained in greater detail below with reference to the enclosed drawings, wherein neither the drawings nor the explanations are to be interpreted as restricting the invention in any manner.

Claims

1. Ultrasonic welding device (1), comprising:

a sonotrode (3); and

a sonotrode carrier (2) which is formed to cause ultrasonic vibrations of the sonotrode (3);

wherein the sonotrode (3) and the sonotrode carrier (2) have in each case a contact face (5) and at least one of the contact faces (5) is roughened at least in sections;

wherein a roughened section (14) of the contact face (5) roughened at least in sections has an mean roughness depth R_z of at least 2.0 µm and/or an arithmetical mean roughness value R_a of at least 0.3 µm;

wherein the mean roughness depth R_z is at most 14 µm and/or wherein the arithmetical mean roughness value R_a is at most 3.0 µm;

wherein the sonotrode (3) is fastened exchangeably to the sonotrode carrier (2) in such a manner that the contact faces (5) are pushed against one another,

wherein the sonotrode (3) is embodied as a flexural resonator which comprises a base body (8) and at least one bending arm (9) which projects from the base body (8);

wherein the sonotrode (3) is fastened exchangeably to the sonotrode carrier (2) via the base body (8) and the base body (8) comprises the contact face (5) of the sonotrode (3).

2. Ultrasonic welding device (1) according to Claim 1,

wherein the sonotrode (3) is fastened exchangeably to the sonotrode carrier (2) via at least one screw (4).

3. Ultrasonic welding device (1) according to Claim 2,

wherein the screw (4) is introduced into a sonotrode opening (13) in the sonotrode (3) and the sonotrode opening (13) is surrounded at least partially by the contact face (5) of the sonotrode (3); and/or

wherein the screw (4) is introduced into a sonotrode carrier opening (12) in the sonotrode carrier (2) and the sonotrode carrier opening (12) is surrounded at least partially by the contact face (5) of the sonotrode carrier (2).

4. Ultrasonic welding device (1) according to Claim 3,

wherein the sonotrode opening (13) is surrounded in a ring-shaped and/or ring segment-shaped manner by the contact face (5) of the sonotrode (3); and/or

wherein the sonotrode carrier opening (12) is surrounded in a ring-shaped and/or ring segment-shaped manner by the contact face (5) of the sonotrode carrier (2).

5. Ultrasonic welding device (1) according to Claim 3 or 4,
wherein the sonotrode opening (13) is surrounded by at least one ring-shaped and/or ring segment-shaped roughened section (14) of the contact face (5) of the sonotrode (3); and/or
wherein the sonotrode carrier opening (12) is surrounded by at least one ring-shaped and/or ring segment-shaped roughened section (14) of the contact face (5) of the sonotrode carrier (2).

6. Ultrasonic welding device (1) according to any one of the preceding claims,
wherein at least one of the contact faces (5) comprises a striped pattern (16) composed of several stripe-shaped roughened sections (14).

7. Ultrasonic welding device (1) according to Claim 6,
wherein the roughened sections (14) of the striped pattern (16) are arranged parallel to one another.

8. Method for producing a sonotrode (3) for an ultrasonic welding device (1) according to any one of the preceding claims, wherein the method comprises:
providing the sonotrode (3) in a state to be processed, wherein the sonotrode (3) is embodied as a flexural resonator which comprises a base body (8) and at least one bending arm (9) which projects from the base body (8) and wherein the sonotrode (3) is fastened exchangeably to the sonotrode carrier (2) via the base body (8) and the base body (8) comprises the contact face (5) of the sonotrode (3); and
processing the sonotrode (3) in order to roughen the contact face (5) of the sonotrode (3) at least in sections,
wherein a roughened section (14) of the contact face (5) roughened at least in sections has an mean roughness depth R_z of at least 2.0 µm and/or an arithmetical mean roughness value R_a of at least 0.3 µm; and
wherein the mean roughness depth R_z is at most 14 µm; and/or wherein the arithmetical mean roughness value R_a is at most 3.0 µm.

9. Method for producing a sonotrode carrier (2) for an ultrasonic welding device (1) according to any one of Claims 1 to 7, wherein the method comprises:
providing the sonotrode carrier (2) in a state to be processed, wherein the sonotrode carrier (2) is configured for generating ultrasonic vibrations in a sonotrode, wherein the sonotrode (3) is embodied as a flexural resonator which comprises a base body (8) and at least one bending arm (9) which projects from the base body (8) and wherein the sonotrode (3) is fastened exchangeably to the sonotrode carrier (2) via the base body (8) and the base body (8) comprises the contact face (5) of the sonotrode (3); and

processing the sonotrode carrier (2) in order to roughen the contact face (5) of the sonotrode carrier (2) at least in sections,

wherein a roughened section (14) of the contact face (5) roughened at least in sections has an mean roughness depth R_z of at least 2.0 µm and/or an arithmetical mean roughness value R_a of at least 0.3 µm; and

wherein the mean roughness depth R_z is at most 14 µm; and/or wherein the arithmetical mean roughness value R_a is at most 3.0 µm.

10. Method according to Claim 8 or 9,

wherein the processing comprises laser treatment and/or mechanical processing by blasting with a blasting agent.