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(54) **METHOD FOR PROCESSING WELDED METALWORK JOINTS BY HIGH-FREQUENCY HUMMERING**

(57) The inventive method relates to a reinforcing treatment of welded metalwork joints using a power ultrasound. The method can be used for mechanical engineering, shipbuilding, bridge engineering and other branches of industry and construction producing welded structures which can be safely used at conditions of static, dynamic and repeated-variable loading. The inventive method involves the step of calculating normalized residual compressive stresses to be produced during the ultrasound impact processing. The stresses are related to the geometrical dimensions of a groove formed when the area disposed along a line between the joint and a base metal is treated. The invention makes it possible to maximally increase the fatigue limit and the cyclic life duration of welded joints.

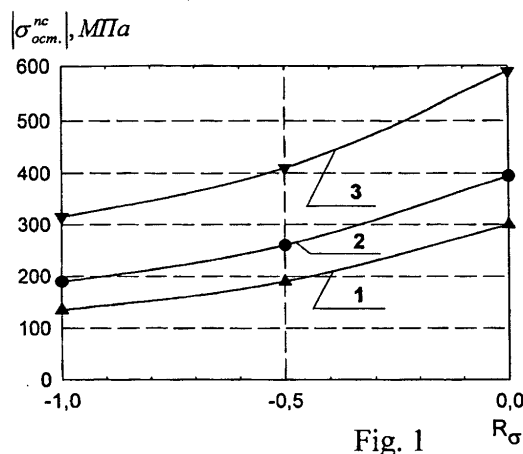


Fig. 1

Description**Technical Field**

[0001] The invention relates to the field of powerful ultrasonic oscillations for surface hardening treatment of metal products and, first of all, of welded joints of metallic structures with shock impulses of high frequency. It can be utilized in mechanical engineering, shipbuilding, bridge engineering and other branches of industries and construction that are dealing with the manufacturing and maintenance of parts and welded structures with responsible designations, working in conditions of dynamic and especially cyclic loading, for prevention of premature fatigue cracks and failures in the zones of welded joints.

Background art

[0002] For hardening and relaxation treatment of both welded joints and structures the different impact methods are employed: magneto-pulsing, low-frequency hammer peening, shoot peening, etc. (Danilov G.I., Leonov V.P., Zolotov I. F. et al. Efficiency of technological methods of cyclic life improving of welded elements of sleet proof offshore platforms// Problems of materials science. - 1996. - No 2. - p. 15-22). However, they differ by considerable power consumption, small efficiency, create considerable noise that often exceeds permissible norms. With this purpose the high power ultrasonic oscillations are also utilized, they are transformed to high-frequency shock impulses of working elements (balls or rods), that affect the surface of the treated parts or structures (Patent of Ukraine No 12741. Published 28.02.97. Bulletin No 1). The striking force of these elements depends on weight, oscillation amplitude of the output tip of the ultrasonic horn, radius of their curvature and the velocity at the moment of contact with the treated surface. The striking force determines the efficiency of treatment of this or that material or welded joint. In the above-mentioned analog, the optimum duration of treatment is calculated with the help of a special operating technological complex. For this purpose an alternating electrical voltage in pulsed conditions is applied to the magnetostrictive transducer. When voltage is absent the transducer continues to oscillate with some attenuation. Upon stabilization of this attenuation the treatment is being finished. However, apparently, that such a method can be applied to a restricted number of materials, mechanical properties of which are changed considerably during the treatment. Stronger materials that require considerable duration of treatment, will be handled less, than it is required, because the attenuation of natural oscillations of the transducer will be thus practically identical to the initial one as in the beginning of the treatment. Therefore for each material and type of welded joint it is necessary to create its own optimum technology of treatment that provides the maximum useful effect with minimum energy and labor consumption. The basis criterion of increasing of cyclic life of welded metallic structures is the creation of normalized on value and character of distribution of residual compressive stresses near the weld-seam zone. These beneficial stresses are induced also in shock treatment with the help of ultrasonics.

[0003] The closest to the proposed method is a known method of treatment of welded metallic structures made mainly from steel, that includes the action by an ultrasonic impact instrument with a given amplitude of oscillations of the horn tip in a zone adjacent to the weld seam, with the purpose of increasing the cyclic life of welded metallic structures by the way of formation of normalized on value and character of distribution residual compressive stresses in the near the weld seam zone (Ukrainian patent No 23001. Published 30.06.98. Bulletin No 3). The selection of oscillation amplitude A of ultrasonic horn tip in this case is carried out using the empirical relationship:

$$2,24 \leq \frac{4\pi A f^2 m}{\sigma_T R^2} \leq 3,36 \quad (1)$$

where f is a frequency of impact impulses, m is a weight of impactor, σ_T is the yield strength of the treated material, R is the radius of the impactor. In this case in welded structures made from low-carbon steels the treatment is performed in a zone, restricted by a line along which the primary recrystallization took place. In welded structures from alloyed and high-strength steels the treatment is performed in a zone, restricted by a line along which low tempering took place. As an optimum value of induced residual compressive stresses the values of the 1.2 - 1.5 of the yield strength of the material in a surface layer with thickness of 0.1 - 0.2 mm, with the total depth of residual stresses extending to 1.0 - 1.2 mm are accepted. The level of stresses is achieved by using the treatment parameters that are chosen from the relation (1) from which the value of amplitude A is calculated. This amplitude can be created with the help of ultrasonic equipment with different power, but the range of optimum powers is not specified in the prototype.

[0004] The main disadvantage of the given method is that the treatment of welded joints of different steels should be made in zones restricted by isothermal curves or low tempering, which need to be determined experimentally. At the same time, compressive stresses normalized on value and character of distribution are assumed to be such that

are equal to their maximum achievable values, exceeding the yield strength of material in 1.2- 1.5 times. However at that the conditions of subsequent cyclic loading are not taken into account such as the coefficient of cycle asymmetry, stress concentration, caused by configuration of the joint, as well as other factors considerably changing the fatigue strength of welded joints and the degree of influence of residual stresses on their cyclic life. Therefore normalized value of residual compressive stresses, created by ultrasonic impact treatment in zones of concentrators, at which the maximum possible increase of limit stress range and fatigue life of joint is reached, should be determined differentially, i. e. depending on above mentioned factors. The value of these stresses depends at other equal conditions on treatment time of given surface area, or productivity of the treatment. But in the known method the amplitude A is determined from the relation (1), and is an invariable parameter, and the treatment time is absent at all. The absence of this parameter does not allow providing specific recommendations related to the regimes of weld strengthening. The mentioned disadvantages do not allow for a unique selection of technological parameters for the considered type of strengthening treatment, that complicates the achievement of expected technical result that leads to the maximum possible increase of the fatigue strength of welded joints of different materials with a considerable decrease of treatment time and without the use of unnecessary power of ultrasonic equipment.

[0005] An important problem in improvement of ultrasonic impact technology or high-frequency peening is the better justified optimization of technological parameters by a criteria of induced residual compressive stresses in the zones of stress concentrators. At the same time it is necessary to determine such values of normalized residual compressive stresses for metals with different strength that will ensure at other equal conditions the maximum possible increase in the limit stress range and fatigue life of welded joints of different types. Besides, it is necessary to create a simplified algorithm of estimation of the optimum regime of strengthening of welded joints, without applying complex preliminary experimental investigations.

Disclosure of the invention

[0006] At the basis of the invention lies the task of improvement of the treatment method of welded joints in metallic structures from steels and alloys by high-frequency forging that includes the application of the ultrasonic impact instrument in zones of stress concentrations, located along the line of seam alloying with the bulk metal through formation of normalized on value residual compressive stresses, at which the minimum cyclic stresses from an external loading achieve the yield stress σ_Y of the material in these zones according to the Smith's diagram, at that depending on cycle asymmetry, type of joint, stress-concentration coefficient and the mechanical properties of the material for realization of boundary cycle, in particular such that does not result in premature fatigue fracture, varies considerably and can be much less than σ_Y . Beside this the treatment of welded joints in steels and alloys of any strength is carried out by ultrasonic impact instruments in zones of stresses concentrations, that is along the line of alloying to the width of 1 - 3.5 mm on both sides from the line with formation of a groove from 0.2 to 1.0 mm in depth.

[0007] The offered method allows providing a targeted high-frequency forging of welded joints of different materials depending on type of seam, the asymmetry in the cycle of external loading and other reasons. To achieve the maximum increase of endurance limit of welded joints the necessity of formation of residual compressive stresses that equal 1.2 - 1.5 of σ_Y - yield stress of material is eliminated. Thus in the region of influence of the sign-alternate stresses from the external loading the necessary levels of residual stresses formed by such treatment, can be much lower than yield stress of metals and alloys, and their value is defined by a calculation method.

[0008] So, the normalizing value of residual compressive stresses in the concentrator zone, depending on the above mentioned factors for welded joints, is determined in accordance with the following relation (Trufyakov V.I., Mikheev P.P., Kudryavtsev Yu. F. Fatigue strength of Welded Structures. Residual Stresses and Strengthening Treatments. Harwood academic publishers.-Vol. 3, part. 2.- 1995.- 100 p.):

$$\sigma_{ocm}^{nc} = \left\{ \sigma_T + \frac{2\alpha_\sigma R_\sigma \left(\sigma_B + \frac{\sigma_T}{\alpha_\sigma} \right)}{(1 - R_\sigma) \left[\frac{\left(\sigma_B - \frac{\sigma_T}{\alpha_\sigma} \right)}{\sigma_a^n} + 2 \right]} \right\} \quad (2)$$

where σ_{ocm}^{nc} are the normalized residual compressive stresses, at which the minimum stresses of the cycle due to external loading in the stress concentrator zone reach the yield stress of material σ_Y ; σ_B is the ultimate strength of a material; α_σ is the theoretical coefficient of stress concentration; R_σ is the coefficient of cyclic asymmetry; σ_a^n is the limiting amplitude of cycle stresses of the original welded joint with high residual tensile stresses.

[0009] As numerous investigations of the authors of the offered invention are showing, for obtaining a maximum durability for a given material at cyclic loading it is necessary to treat in all cases only a zone with a width not more than 2 - 7 mm, that is 1.0 - 3.5 mm to both sides from the line of seam alloying with the bulk metal, where the stress concentrators are localized and maximum tensile residual stresses of the first kind are formed, and also different weld defects are accumulated. Therefore the treatment of wider zones, as in the prototype, does not provide a useful effect, and only increases the treatment time. The treatment regimes (oscillation amplitude of the ultrasonic horn, the size and amount of impactors, the rate of movement of the instrument along a seam, the force of pressing the instrument to a part) are selected such as to provide a necessary level of residual compressive stresses. At the same time after treatment a groove remains 2 - 7 mm wide and from 0.2 to 1 mm deep. The sizes of the groove are connected to the value of the compressive stresses; therefore its measurements and visual inspection considerably simplify the estimate of the end and quality of the treatment process. The preliminary definition of normalized values of residual compressive stresses σ_{ocm}^{nc} that are induced by high-frequency forging in stress concentration zones, provides the greatest possible increase of endurance strength of welded joints with a considerable decrease of its application duration and lowering of the oscillation amplitude of ultrasonic horn. This leads to lowering of labor and energy consumption through the use of less powerful ultrasonic equipment. It is established experimentally that for maintenance of a given amplitude of ultrasonic horn tip in an interval 20 - 35 microns during treatment of materials of low and medium strength, equipment with power 0.25 - 0.5 kW can be used. For high-strength materials the necessary power reaches 1.0 kW. Such an approach allows optimizing the technology of ultrasonic impact treatment taking into account practically all types of welded joints and different materials and to lower their cost price. Also in welded joints of all types only narrow zones 2 - 7 mm wide and 0.2 - 1.0 mm deep are being treated on line of seam alloying with the bulk metal. The strain level and, accordingly, σ_{ocm}^{nc} depend on the width and the depth of the groove formed during treatment. Therefore its sizes can be used for a visual inspection of treatment regimes instead of measuring the σ_{ocm}^{nc} that conduct mainly on control samples.

Brief description of the drawings

[0010] Figure 1 presents a graph of the dependence of the normalized compressive residual stresses σ_{ocm}^{nc} on the coefficient of cycle asymmetry R_Φ of external loading for butt joint steels, grouped in three classes of strength: (low-carbon steels - $\sigma_Y \sim 300$ MPa (1), low alloy steels - $\sigma_Y \sim 400$ MPa (2), high strength steels $\sigma_Y \sim 600$ MPa (3)). Figure 2 shows as well a graph of dependence of σ_{ocm}^{nc} on R_Φ for the same steels placed in the same order: 1 - low-carbon steel, 2 - low alloy, 3 - high-strength steel, but for welded joints with fillet welded seams.

The presented data shows the effect of cycle asymmetry on the optimum value of compressive residual stresses that should be induced in the zones of stress concentrations, i.e. along the weld toe zone by high frequency peening. They should provide a maximum possible increase of the limit fatigue strength range and increase of the cyclic fatigue life of welded joints. From Fig. 1 and Fig. 2 it can be seen that the necessary levels of residual stresses that had to be reached with the help of surface deformation, can be much lower than the yield stress σ_T of considered material and only in the of-zero (asymmetric) cycle at $R_\Phi = 0$ they are equal to σ_T . In practical applications such relationships are calculated with the help of computing programs for construction materials of different grades and various types of welded joints and are stored in computer memory. When required these data is used for choosing the regimes of high-

frequency peening.

Different embodiments of the description

[0011] Realization of the treatment method of welded joints of metallic structures is based, firstly, on calculations of normalized residual compressive stresses σ_{ocm}^{nc} that should be created in concentrators zone along the seam to provide the greatest possible increase of fatigue durability. After definition of σ_{ocm}^{nc} it is necessary to select an optimum regime of treatment with the help of ultrasonic generator and a magnetostrictive or a piezoceramic transducer, the oscillations of which are transformed to high-frequency impact impulses with the help of pins impactors of different diameter. Depending on the strength of treated material a selection of the power of ultrasonic equipment in an interval 0.25 - 1.0 kW, the amplitude of ultrasonic horn (20 - 35 microns), the diameter of the pins (2 - 7 mm) is made. Power and amplitude are directly proportional to Φ_V , and the diameter of the pins must be chosen larger for less strong materials. The basic parameters of treatment regime are: the diameter of the pins - d , the quantity of pins - n , the radius of pin's working part fillet - R , the efficiency of treatment - $Q = L/T$, where L - is the length of seam site that is being treated, T - is the time of treatment, A - is the oscillation amplitude of ultrasonic horn tip, F_{st} - is the clamping force of the instrument to the part, V - is the rate of instrument movement along the seam. F_{st} is equal to 40-50 N and is constant for all treatment regimes. Optimization of the regimes is carried out on samples in order to reach the set values of σ_{ocm}^{nc} in the shortest time. These residual stresses are measured by X- ray, ultrasonic, holographic or other non-destructive method and the treatment time is determined. After that the size of the groove that is formed along the line of seam alloying with bulk metal is measured. The width and the depth of the groove are related to the amount of strain and accordingly to σ_{ocm}^{nc} , therefore in the future during the treatment of structures they are taken into consideration.

[0012] Example. For high frequency peening a steel having medium mechanical strength is chosen (for instance 15XGCHA) and using equation (2) the σ_{ocm}^{nc} is calculated for a butt welded joint and symmetric loading cycle. For this case $\sigma_{ocm}^{nc} = 180$ MPa. The given stress can be determined also with the help of the curves (Fig. 1). Then, we chose the oscillation amplitude $A = 25$ microns. Select the diameter of the pins $d = 3$ mm, number, $n = 4$ placed in a line, and the radius of the tip, $R = 3$ mm. The advancement rate of the instrument V is kept constant and is approximately 1 m/minute. The length of the weld seams that are treated is $L = 0.28$ m. Narrow zones along the line of seam alloying with the base material are treated in a few passes with the advancement rate V and with intermediate measurements of σ_{ocm}^{nc} . When these values coincide with the calculated or slightly exceed them (by 3-5 %), the treatment is stopped and the total treatment time T is registered. In the presented example $T = 1.12$ min, then the treatment efficiency of the considered sample is $Q = 0.25$ m/min. In future structures from this steel are treated with the same efficiency. After the treatment a groove remains on the surface of the sample with a width $b \sim 3$ mm and depth $h \sim 0.5$ mm. The visual inspection of the groove allows to control the uniformity and quality of the treatment and if necessary allows to repeat the treatment of a region where the groove is narrowed or there is a weld defect.

Industrial Application

[0013] The starting (after welding) and treated samples had been tested in a fatigue testing machine ZDM-10 according to the variable sign bending scheme ($R_\Phi = -1$) with a frequency 12 Hz and a level of stresses equal to 0.25 σ_S . The average values of fatigue life for the starting and treated samples constitute 10^5 and 7×10^5 cycles, respectively.

[0014] The technical and economical efficiency of the method is determined by an increase in cyclic longevity and increase in the warranty life of the metal structures with a simultaneous optimization of the process of high-frequency peening of weld seams due to lowering of the power of the ultrasonic generators and a considerable lowering of the treatment time.

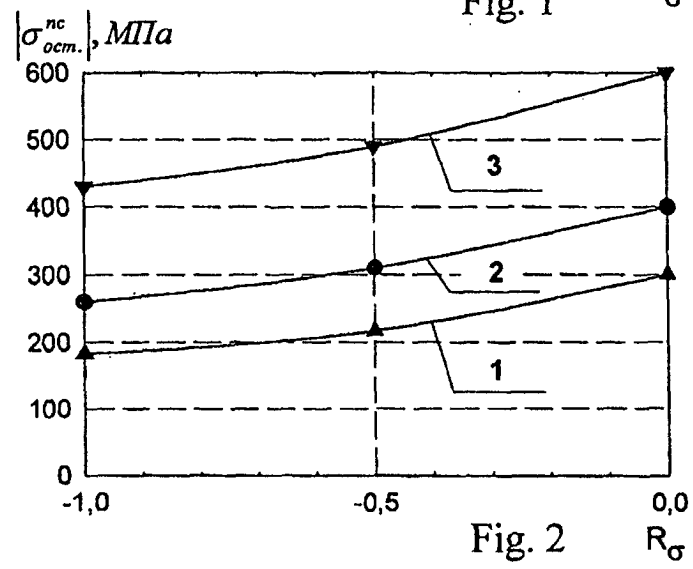
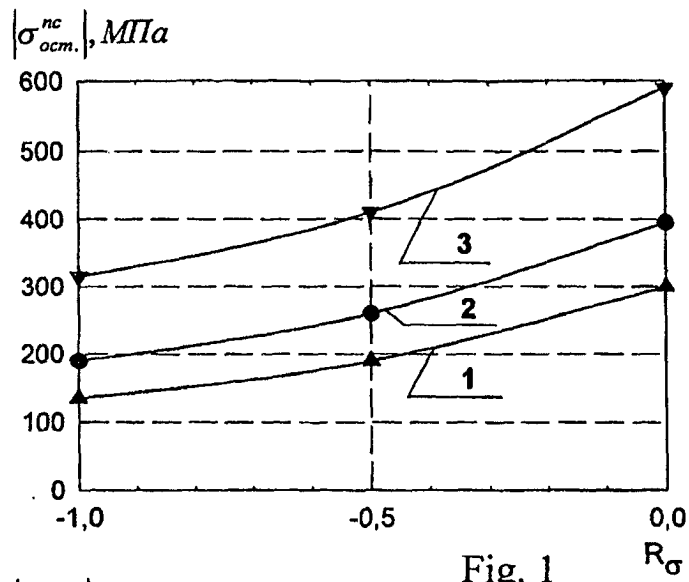
Claims

1. A method of treatment of welded joints of metallic structures by high-frequency peening that includes the action by an ultrasonic impact device with a predetermined oscillation amplitude of the horn tip in the zone adjacent to the weld seam, **characterized in that** the treatment is performed in stress concentration zones that are located along the line of melting of the weld seam with the base metal, by inducing normalized on value residual compressive stresses σ_{ocm}^{nc} , at which the minimum cyclic stresses from external loading reach the yield stress of the material σ_T in these zones according to the known Smith's diagram, at the same time depending on the cycle asymmetry, the type of welded joints, the stress concentration coefficient and the mechanical peculiarities of the material, the required value of σ_{ocm}^{nc} is calculated from the expression:

$$\sigma_{ocm}^{nc} = \left[\sigma_Y + \frac{2\alpha_\sigma R_\sigma \left(\sigma_S + \frac{\sigma_Y}{\alpha_\sigma} \right)}{(1 - R_\sigma) \left[\frac{\left(\sigma_S - \frac{\sigma_Y}{\alpha_\sigma} \right)}{\sigma_a'} + 2 \right]} \right],$$

where σ_{ocm}^{nc} are the normalized residual compressive stresses, at which the minimum stresses of the cycle due to external loading in the stress concentration zone reach the yield stress of material σ_Y ; σ_B is the ultimate strength of a material; α_σ is the theoretical coefficient of stress concentration; R_σ is the coefficient of cyclic asymmetry; σ_a^n is the limiting amplitude of cycle stresses of the original welded joint with high residual tensile stresses with high tensile residual stresses, and after that the treatment of the seam is conducted according to chosen regimes, to achieve the determined σ_{ocm}^{nc} in shortest time.

2. A method according to claim 1 that differs in that in welded structures made from steel and alloys of different strength during the high-frequency peening due to deformation of the metal a groove is formed 2 - 7 mm wide and 0.2 - 1 mm deep, the geometrical parameters of which depend on treatment regime and are connected with the value of σ_{ocm}^{nc} for specific material and type of welded seam.



INTERNATIONAL SEARCH REPORT

International application No.

UA02/00025

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According to International Patent Classification (IPC) or to both national classification and IPC 7		
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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	SU 130528 A (B. I. LAZAREV et al) 1960, the claims	1-2
A	SU 1118509 A (JU. YA. KHRISTOEV et al) 15.10.1984, the claims	1-2
A	SU 1481044 A2 (INSTITUT ELEKTROSVARKI) 23.05.1989, the abstract	1-2
A	FR 2444719 A1 (ALSTHOM-ATLANTIQUE) 18-7-1980, the claims	1-2
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