IIW/IIS - DOCUMENT XIII - 1757 - 99

GUIDE FOR APPLICATION OF ULTRASONIC IMPACT TREATMENT IMPROVING FATIGUE LIFE OF WELDED STRUCTURES

¯.S. Statnikov

Applied Ultrasonics, P.O. Box 100422, Birmingham, Alabama 35210, USA

Northern Scientific & Technology Company
6 Voronin St., Severodvinsk, Arkhangelsk Region 164500, Russia

Abstract

In recent years, in the context of fatigue life improvement methods, Ultrasonic Impact Treatment (UIT) has attracted a particular attention.

Independent expert assessments of this method provide indications of its effectiveness, workability, compatibility with welding fabrication and repair processes, controllability, simplicity in use and in quality control, high stability and reproducibility of results.

The last feature (reproducibility) is largely attributable to the proper preliminary tool and treatment parameters selection for specific materials, welded joint types and service conditions.

Practical use of this method in the fabrication or repair of welded metal structures requires the establishment of guidelines for proper selection of UIT parameters. This selection is made based on desired results of treatment, types of treated materials and welded joints.

The paper is submitted for consideration to Commission XIII
of the International Institute of Welding
1999 Lisbon, Portugal

1. Introduction

Ultrasonic Impact Treatment (UIT) was developed to improve quality, carrying capacity and life of welded joints in metal structures with long service life [1]. Positive results of fatigue testing [2, 3] and UIT applications [4] are well known. IIW UIT Specification was issued in 1996 [5]. These studies and technical applications were preceded by careful testing of UIT parameters for specific welded joints and materials at the laboratory of NSTC in Severodvinsk, Russia and at the E.O. Paton Electric Welding Institute in Kiev, Ukraine. In the past two years UIT has been further developed by Applied Ultrasonics in Birmingham, Alabama, USA in cooperation with NSTC. Additional data on UIT efficiency have been obtained [6, 7]. Algorithms of UIT operational procedures have been developed for fabrication, maintenance, and repair of welded joints with considerations for metal properties and welded joint types. The design and technical parameters of UIT equipment are improved and new series of equipment is fabricated. This document is intended for specialists in fabrication of welded structures and in fatigue life improvement. It describes the current stage of UIT method development and provides basic information to assist in selection of UIT operational procedures with the aim to increase the fatigue strength of welded structures.

2. UIT Mechanism and its Effect on Welded Joint Materials

The UIT mechanism of operation is represented in Fig. 1 and Fig. 2. The following sequential effects are taking place during UIT operations:

- forced oscillations 1 of ultrasonics transducer **I**;
- transfer of ultrasonic oscillations 1 to a replaceable (removable) concentrator of oscillating velocity (waveguide) **II**;
- impact of the output end of the waveguide **II** upon the indenter **III**;
- impact of the indenter **III** upon the treated surface of the workpiece **IV**;
- transformation of the oscillation 1 into force impulses 2 at the output end of the waveguide **II** and surface **IV** during the impact of the indenter **III** on the surface of the workpiece **IV**.

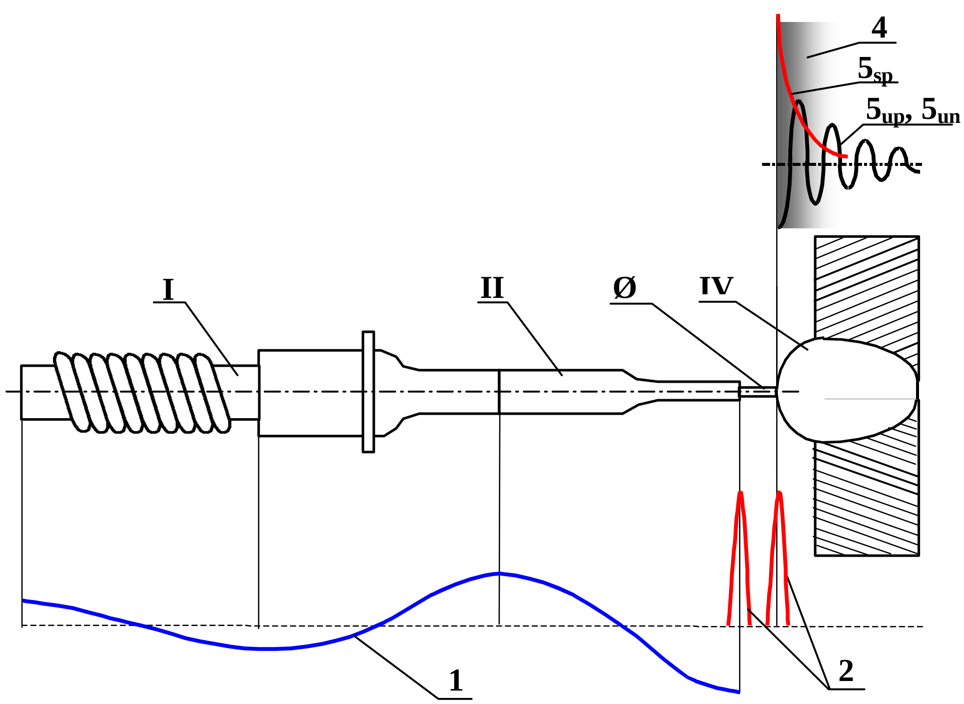


Fig. 1 UIT Mechanism

Impacts of the indenter **III** upon the workpiece surface **IV** are accompanied by one of the following interactions between the indenter **III** and the workpiece **IV** during the impact:

- ultrasonic periodic forced oscillations 3_{po} of the indenter **III** in the workpiece material **IV** with continuous contact between indenter and treated surface (ultrasonic periodic impact);
- ultrasonic non-periodic forced oscillations 3_{np} of the indenter **III** with indenter **III** rebounding off the workpiece surface **IV** (ultrasonic non-periodic impact);
- single contacts 3_c of the indenter **III** with its rebound off the workpiece **IV**.

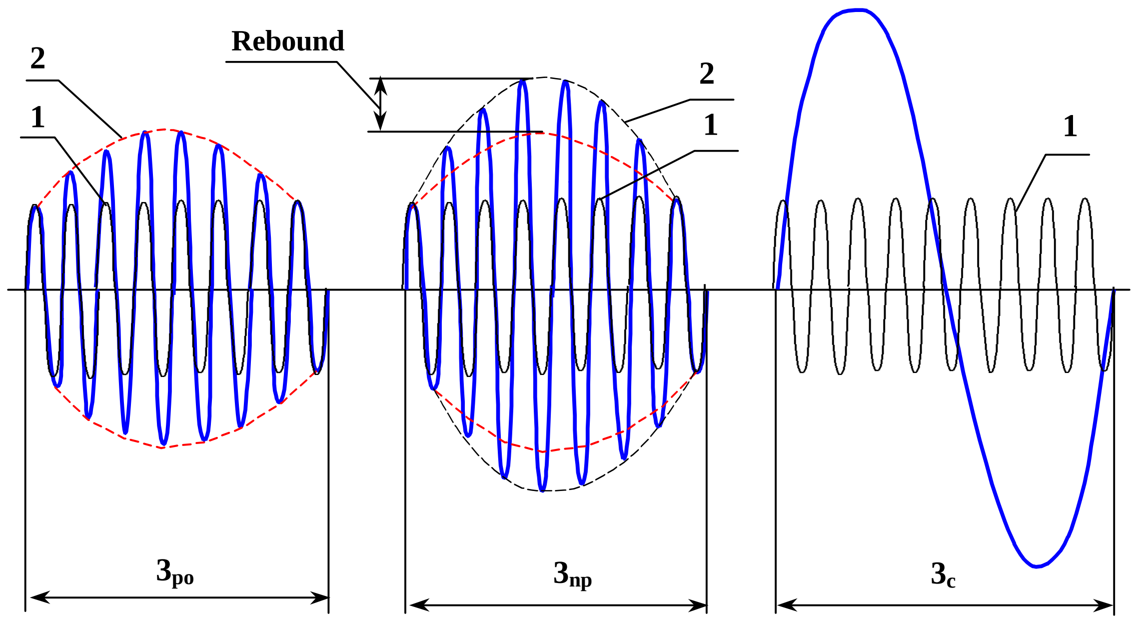


Fig. 2 Interactions between indenter III and workpiece IV during impact

Force pulses 2 initiated by the waveguide II impact upon the indenter III, and then by the indenter III upon the workpiece IV result in plastic deformation 4 at and under the surface of the workpiece IV. These impulses also set off forced oscillations 3 of the indenter III in the workpiece material IV, as well as the indenter III rebound off the workpiece surface IV.

The indenter **III** oscillations 3_{po} in the workpiece material **IV** during the impact of the indenter **III** upon the workpiece **IV** and plastic deformation 4 of the workpiece material **IV** excite ultrasonic periodic stress waves 5_{up} in the workpiece **IV**.

Oscillations 3_{np} of the indenter **III** with a rebound off the workpiece surface **IV** during the indenter **III** impact upon the workpiece **IV** and plastic deformation 4 of the workpiece material **IV** set off propagation of ultrasonic (non-periodic) stress pulses 5_{un} in the workpiece.

Single contacts 3_c of the indenter **III** with its rebound off the workpiece **IV** cause propagation of single stress pulses 5_{sp} in the workpiece.

The energy of force pulses 2 and oscillations 3 during indenter **III** impact on the workpiece **IV** is sequentially utilized for plastic deformation 4 of the workpiece surface **IV**, saturation of the near-surface layer of the workpiece material **IV** with plastic deformations, oscillations and pulsed deflection of this layer during the impact, and creation of ultrasonic stress waves and force pulses 5 in the volume of treated material.

Plastic deformation 4 of the treated material induces compressive stresses at the near-surface layer of the workpiece **IV.** Consequently, ultrasonic stress waves and force pulses 5 relax residual (welding) stresses in the depth of treated materials.

Indenter **III** impacts upon the workpiece surface **IV**, indenter **III** oscillations 3 during these impacts and rebounds off the surface can have features of random and controlled events. The nature of these events depends on the algorithm of oscillating system excitation **I-II-III-IV** and impact control algorithm in this system.

3. UIT Basic Parameters

UIT is inducing compressive stresses $äσ_y$ in the near-surface layer of the workpiece, is redistributing and relaxing (reducing) residual stresses in the welded joint and in whole structure.

Each of these effects defines new deflected mode $Ô_{dm}$ of the welded joint material and welded structure treated by UIT, and is a function of the force pulse (mv) at the treated surface and impact energy (mv^2) upon this surface during UIT.

$$Ô_{dm}=\mathbf{F}(mv,\ mv^2),$$

where:

m is the equivalent mass of the oscillating system **I-II-III-IV** reduced to the output end of the waveguide **II** when applying UIT to induce compressive stresses in the surface layer of the workpiece **IV** ($m_{äσ_y}$) and reduced to the surface of the workpiece **IV** in the treatment area when using UIT to redistribute or relax (reduce) residual welding stresses in the workpiece IV material depth (m_{rr}). Accordingly,

v is the oscillating velocity at the output end of the waveguide **II** when applying UIT to induce compressive stresses in the surface layer of the workpiece **IV** ($v_{äσ_y}$) and at the indenter **III** when applying UIT to redistribute or relax (reduce) residual welding stresses in the workpiece material **IV** depth (v_{rr}) respectively. Therefore:

$$m_{äσ_y} = Ì_{\mathbf{I-II}} \cdot Óî + Ì_{\mathbf{III}} \cdot Óî_{\mathbf{III}}, \qquad (1)$$

where:

$Ì_{\mathbf{I-II}}$ is the full mass of the oscillating system **I-II**;
$Óî$ is the functional factor of displacement distribution in the oscillating system **I-II**;
$Ì_{\mathbf{III}}$ is the full mass of the indenter **III**;
$Óî_{\mathbf{III}}$ is the functional factor of displacement distribution in the indenter **III**.

$$m_{rr} = Ì_{\mathbf{I-II}} \cdot Óî + Ì_{\mathbf{III}} \cdot Óî_{\mathbf{III}} + Ì_{\mathbf{IV}} \cdot Óî_{\mathbf{IV}}, \qquad (2)$$

where:

$Ì_{\mathbf{IV}}$ is the full mass of the workpiece **IV** as defined by its volume which is included in the oscillating system **I-II-III-IV;**

$M_{\mathbf{IV}}$ is the mass of the volume of material within work piece 4 which forms part of the oscillating system **I-II-III-IV;**
$Óî_{\mathbf{IV}}$ is the functional factor of displacement distribution (fluctuating ultrasonic and pulse stress) in the volume $Ì_{\mathbf{IV}}$.

In the calculation of the equivalent mass m**,** it is assumed that in the oscillating system **I-II-II-IV** and its elements with distributed parameters the instantaneous displacement:

for subsystem **I-II-III**:

$$î_{×}=\pm î_0 \cdot \sin(øô \quad x), \qquad (3)$$

for workpiece **IV** material:

$$î_{×}=\pm î_0 \cdot e^{-βx} \cdot \sin(øô \quad x), \qquad (3à)$$

where:

$î_0$ is the maximum displacement amplitude at the output end of the waveguide **II**, indenter **III** or in the workpiece material **IV** respectively;

ø is the oscillation frequency of the waveguide **II** or indenter **III** respectively;

$k = \frac{w}{c}$ is the wavenumber of the waveguide **II** or indenter **III** material respectively.

c is the sonic velocity in the material of the waveguide **II,** indenter **III** or workpiece **IV** respectively**;**

x is the linear coordinate of displacement;

β is the loss factor in the material of a given welded joint.

Hence when inducing compressive stress in the material **IV,** the instantaneous oscillating velocity in the system **I-II-III** is defined as follows:

$$v_{ä\sigma_y} = \pm î_0 \bullet ø_{ä\sigma_y} \bullet \cos(ø_{ä\sigma_y} \bullet ô \quad x), \qquad (4)$$

for workpiece material **IV**:

$$v_{ä\sigma_y} = \pm î_0 \bullet ø_{ä\sigma_y} \cdot e^{-\beta x} \bullet \cos(ø_{ä\sigma_y} \bullet ô \quad x), \qquad (4à)$$

where:

$ø_{ä\sigma_y}$ is the oscillation frequency of the indenter **III**.

With redistributing and relaxation of residual stresses in the material **IV,** the instantaneous oscillating velocity in the system **I-II-III** is found from:

$$v_{rr} = \pm î_0 \bullet ø_{rr} \bullet \cos(ø_{rr} \bullet ô \quad x), \qquad (5)$$

for workpiece material **IV**:

$$v_{rr} = î_0 \bullet ø_{rr} \bullet e^{-\beta x} \bullet \cos(ø_{rr} \bullet ô \quad x), \qquad (5à)$$

where $ø_{rr}$ is the oscillation frequency at the output end of the waveguide **II**.

Stress distribution in the workpiece material **IV** in depth x and at the surface is defined as:

$$\sigma_x = \sigma_s \bullet e^{-\beta x}, \qquad (6)$$

where σ_s is the surface stress.

Given depth of relaxation h_{rr} and associated minimum fluctuating (ultrasonic) stress level in the workpiece **IV** $\sigma_{min_{rr}} = (0{,}15 \div 0{,}2)\sigma_y$, the ultrasonic fluctuating stress at the workpiece surface **IV** can be defined as:

$$\sigma_{Srr} = \frac{\sigma_{min_{rr}}}{e^{-\beta h_{rr}}}, \qquad (7)$$

where h_{rr} is the preset depth of residual stress relaxation.

If it is assumed that at a given depth $h_{ä\sigma_y}$ of plastic deformation the residual stress is equal to σ_y, then at the surface of the workpiece **IV** this stress is found from:

$$\sigma_{Sä\sigma_y} = \frac{\sigma_y}{e^{-\beta h_{ä\sigma_y}}}, \qquad (8)$$

where $h_{ä\sigma_y}$ is the given depth of the plastic deformation.

From both (7) and (8) relations, design and controlled parameters of UIT are determined.

Therefore, **initial parameters** to define UIT conditions are:

- welded joint type and geometry;
- stress concentration factor of a welded joint;
- mechanical properties of the welded joint material (yield strength σ_y, ultimate strength $\sigma_{â}$, sonic velocity c and loss factor β);
- preset fatigue characteristics of a given welded joint (fatigue limit σ_R and life N of a welded joint);
- oscillating system **I-II** behavior.

Preset UIT parameters:

- plastic deformation depth $h_{ä\sigma_y}$;
- depth of stress redistribution and relaxation h_{rr};
- weld toe geometry after UIT.

Design and controlled UIT parameters:

- mass $M_{\mathbf{III}}$ and dimensions of the indenter **III**;
- force pulse (impulse) mv;
- impact energy mv^2;
- oscillating frequency $ø_{rr}$ of the waveguide end **II**;
- impact frequency $ø_{ä\sigma_y}$ of the indenter **III**;
- oscillating amplitude $î_0$ of the waveguide end **II**;
- radius **R** of the indenter contact surface **III**.

4. UIT equipment

UIT of welded joints is performed with equipment consisting of an ultrasonic tool with operating frequency of 27, 36, 44 kHz and the associated ultrasonic generator (Fig.3).

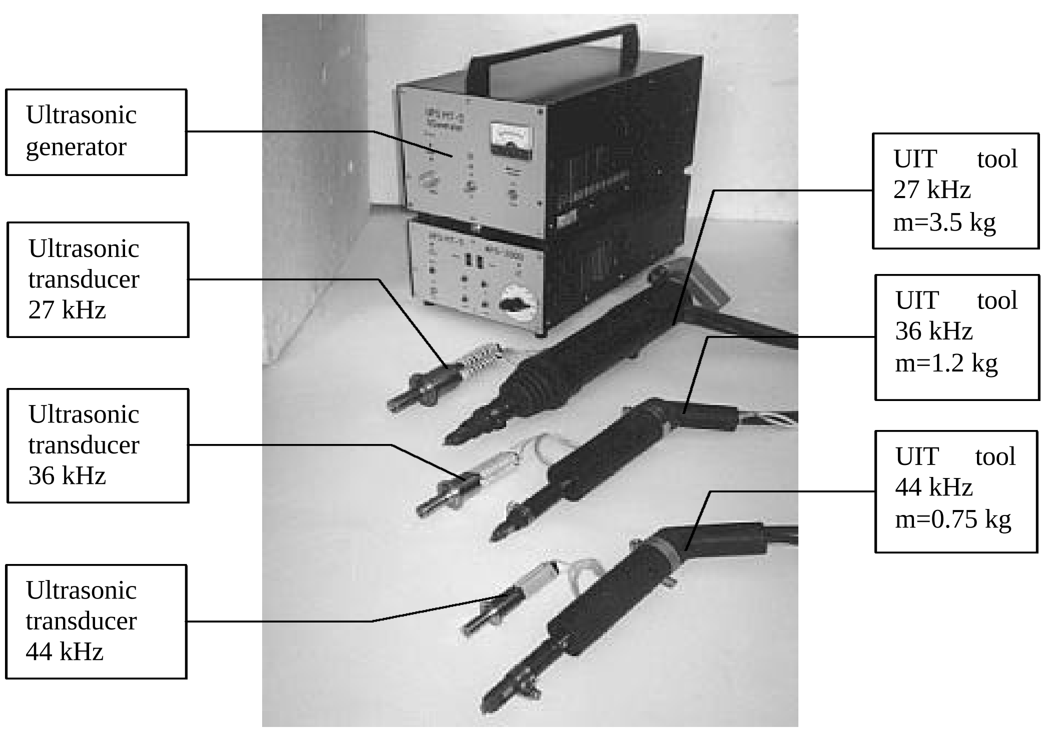


Fig. 3 UIT Equipment

Specifications of Ultrasonic Generator UIP MSP-5

Output power Output power adjustment	600 1800 VA
Supply main voltage	stepped (4 ranges, 6 steps in each)
Supply main frequency	110/220 V
Max output voltage	60/50 Hz
Operating frequency range	100 V
Overall dimensions	25 28,0 kHz
Weight: - generator	520 x 240x 470 mm
- power supply	12,5 kg
Max cable length to connect generator and tool	19 kg
Cooling	80 m
Automatic frequency adjustment	air
Mechanical resonance indication	over entire range
Relative measurement of displacement amplitude of the waveguide output end	light
	needle indicator

Specifications of Ultrasonic Tools

Parameter	Operating frequency, kHz		
	27*	36*	44*
Design	For manual treatment For automatic treatment		
Rated consumed power, VA	600-1200	300-800	200-500
Excitation voltage, V	60-110		
Bias current, À	10-15	6-10	5-8
Oscillating amplitude of the waveguide output end, micron	35-40	30-35	25-30
Treatment speed in manual mode, m/min (m/h)	0,3 1,5 (18 90)		
Treatment speed in automatic and semi-automatic mode, m/h	3 30		
Overall dimensions of the manual tool, mm	455ı85ı80	380ı110ı50	330ı100ı40
Manual tool weight, kg	3,5	1,2	0,75
Cooling	Liquid		
Replaceable tool heads	Straight, angle		
Indenter diameter, mm	2-5		
Hardness of the indenter work face	62-64 HRC		

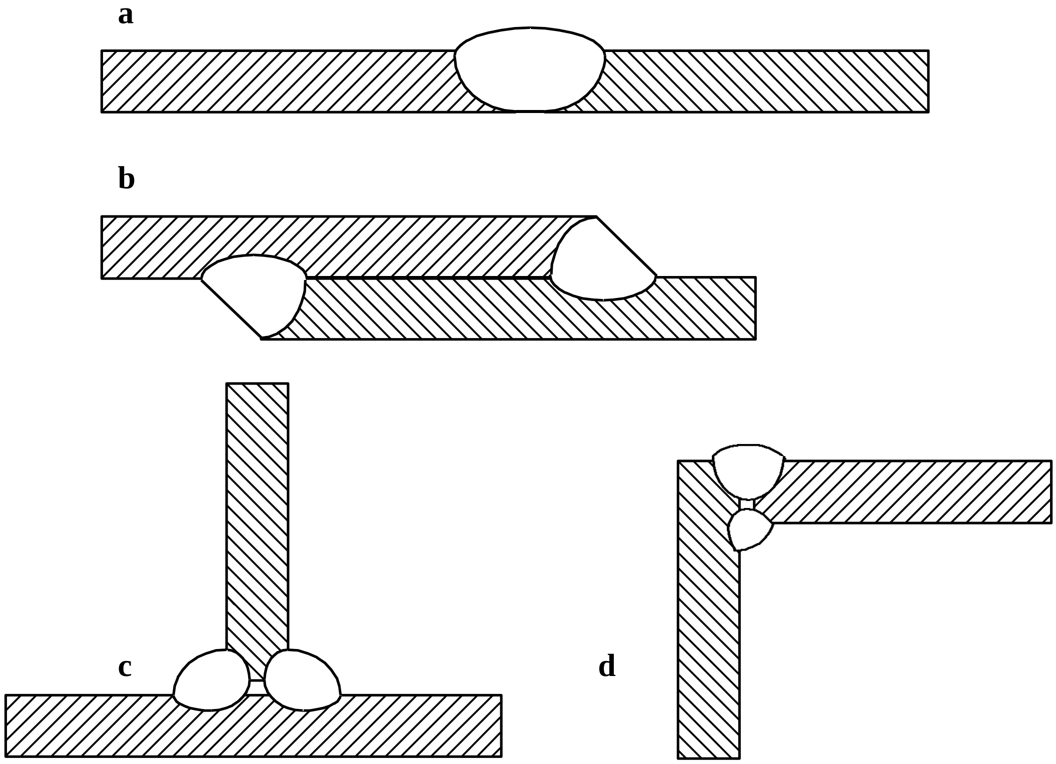
*Note: 27 kHz   production unit; 36 Ł 44 kHz   prototypes.

Manual ultrasonic tools installed on the welding machine travelers can be usable for automatic UIT. Special tools can be designed based on the standardized ultrasonic transducers developed and manufactured by NSTC (Fig. 3).

5. Types of Welded Joints

In actual practice, UIT has demonstrated the possibilities of applying this method in production, assembly and repair of essentially all basic welded joint types presented in Fig. 4÷ 8.

5.1 Field and repair welded joints are made in all welding positions: flat, horizontal-vertical, overhead and vertical.



a) butt joint c) T joint
b) lap joint d) corner joint

Fig. 4 Basic Types of Field Welded Joints

5.2 Butt joints are made both with one and two-sided welds. Square and groove preparation is usable (Fig. 5).

a) square groove weld

b) single V groove weld

c) double V groove weld

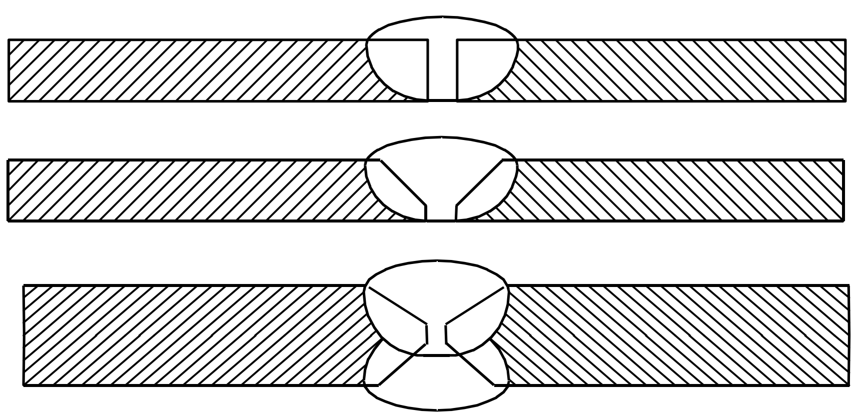


Fig. 5 Welded butt joints

5.3 Lap joints have flat faced and convex welds with different leg (overlap) ratio as depicted in Fig. 6. In order to reduce stress concentration, the transversal welds are made with 1:2.5 overlap ratio with subsequent grinding (reinforcement removal).

à) 1:1 overlap ratio

b) 1:1.5 overlap ratio

c) 1:2.5 overlap ratio

d) 1:2.5 overlap ratio with grinding

1 ground surface

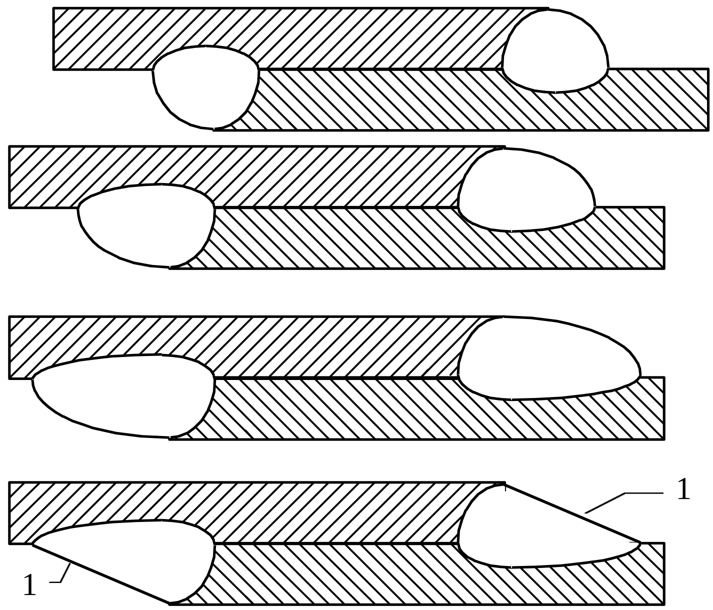
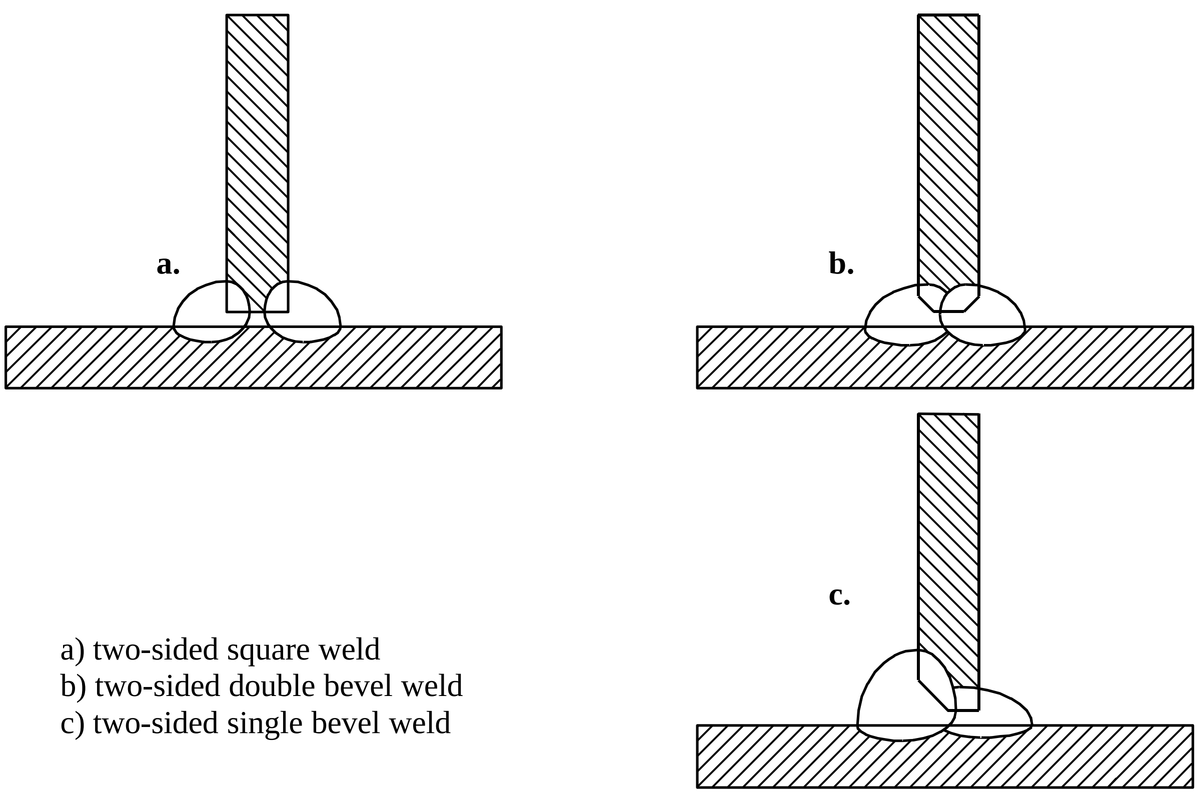


Fig. 6 Welded lap joints with different leg ratio

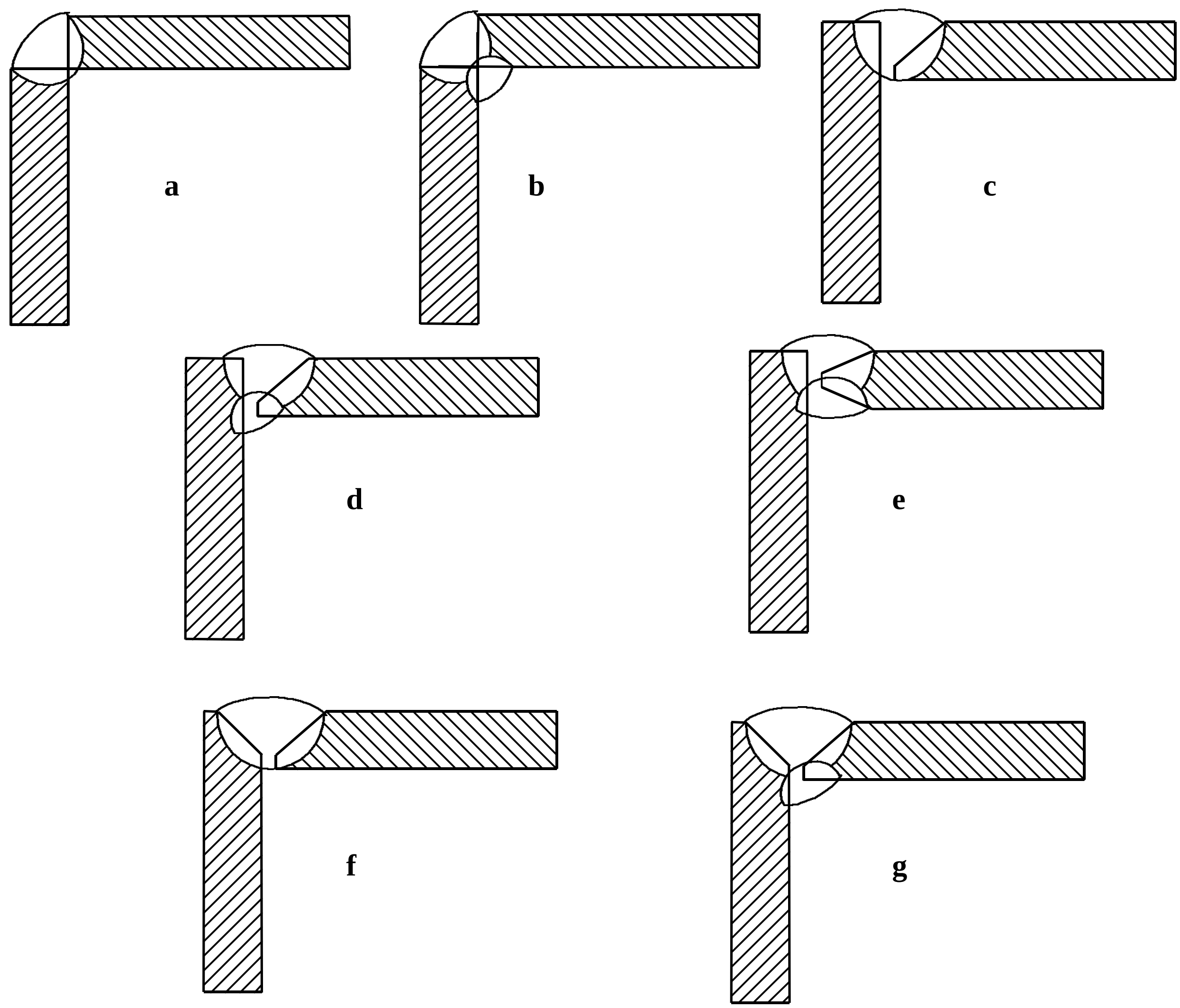
5.4 Fillet welds in T-joints are made either without groove preparation or as single and double bevel welds (Fig. 7).



a) two-sided square weld
b) two-sided double bevel weld
c) two-sided single bevel weld

Fig. 7 Welds in T-joints

5.5 Welds in corner joints (Fig. 8) may be one and two-sided. Square, single and double bevel preparation is used.



a) outside weld
b) outside and inside welds
c, f) single bevel one-sided weld
d, g) single bevel two-sided weld
e) double bevel weld

Fig. 8 Welds in Corner Joints

6. Welded Joints Complications

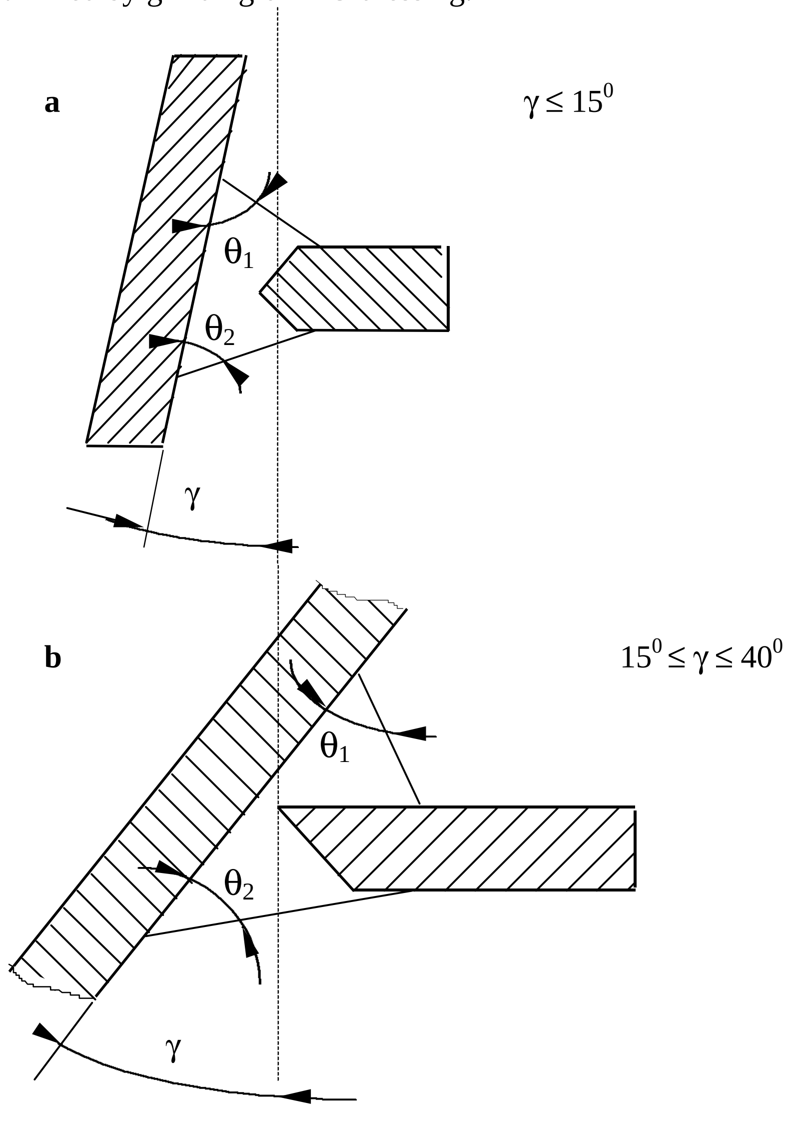
In the development of the UIT application, the designer shall define most loaded and critical welded joints. Thereupon a decision to apply UIT is taken and a list of associated welded assemblies is made out.

The list includes two assembly classes:

- Class 1: assemblies subject to the most unfavorable conditions;
- Class 2: other assemblies.

The set up for UIT application is selected depending on the loading condition, configuration and size of the welded assembly (see paragraph 7.6).

Welds, specifically in T-joints, with flank angle θ over 60” have the most unfavorable geometry (Fig. 9) with high service stress concentration factor. In normal practice, such geometry of the weld is optimized by grinding or TIG dressing.



γ - angle between welded elements

θ_1; θ_2 - flank angles

Fig. 9 Defining Flank Angles When Setting UIT Type

7. UIT Procedures

7.1 UIT and its parameters for particular assemblies and joints in welded metal structures are set by developer, designer or technologist.

This is done on the basis of results of experimental tests of UIT efficiency in specific welded joint type, evaluation or prediction of fatigue limit and fatigue strength (life) of these welded joints, and also considering experience in fabrication and maintenance of welded structures with use of UIT.

7.2 UIT treated welds are indicated by  **symbol.**

This symbol is drawn on the reference line as shown in Fig. 10. UIT is applied over the entire length of the marked weld (Fig. 10a) or to the weld section of length defined from start of the weld (Fig. 10b).

UIT variation for the weld is indicated by symbol drawn on the reference line or in the drawing specification as per Fig. 12.

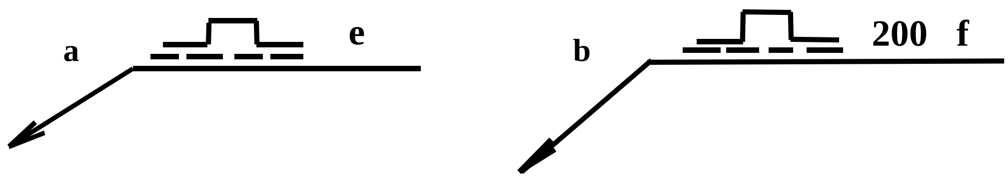
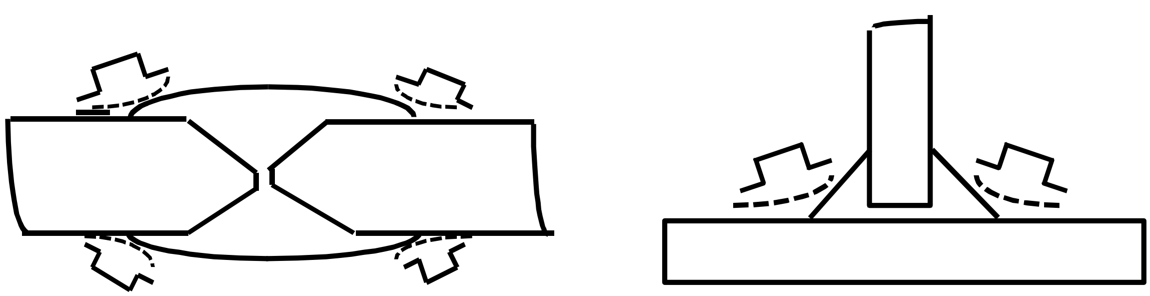


Fig. 10 Marking of UIT treated welds

7.3 Butt joints are treated by UIT at both sides of the weld toes and from both sides of the welded joint (Fig. 11a).

Typically, transition between the weld and load-carrying structural member is treated by UIT in fillet welds in corner, lap and T joints. Two-sided welds in T joints are treated from both sides (Fig. 11b).



a b

Fig. 11 UIT Areas in Welds

7.4 UIT variation for specific welded assemblies can be provided and described in the drawing specification, procedures or separate sketches.

Fig. 12 illustrates UIT variations. As an example, T joints are shown.

1) base metal; 2) weld metal; 3) weld toe; 4) UIT treated weld toe; 5) TIG dressing area; 6) fusion line between additional bead and weld metal; 7) fusion line between additional bead and base metal; 8) additional bead (preliminary deposition); 9) UIT treated transition between the additional bead and the base metal; 10) UIT treated transition between the additional bead and the weld metal; 11) additional bead (deposition after making of a weld).

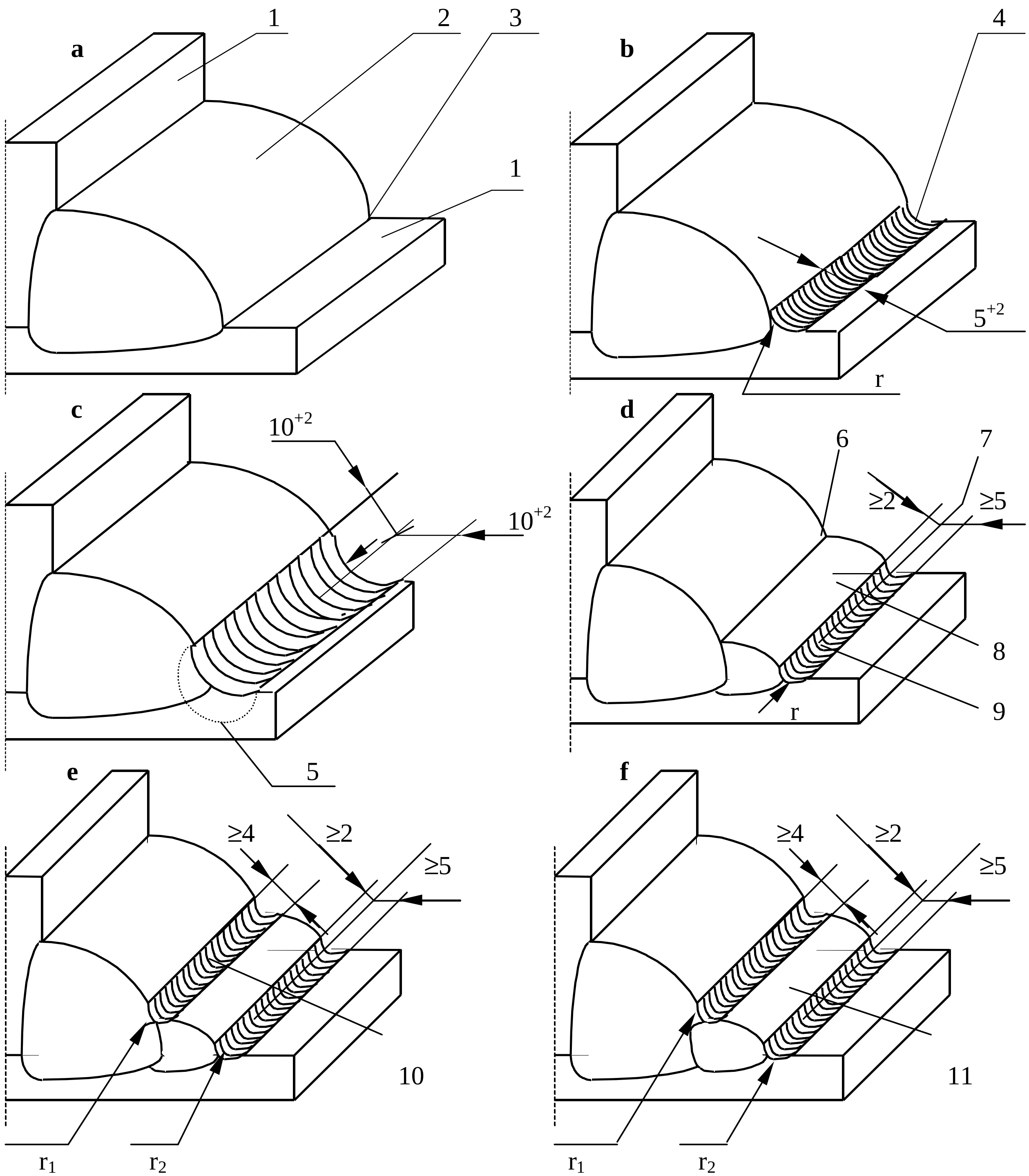


Fig. 12 UIT variations for T joints

a) as welded;
b) formation of a smooth transition (groove), 3 - 5mm in radius, at the weld toe by UIT;
c) making of a transition of large radius r = 5-8mm by TIG dressing and UIT;
d) preliminary deposition of the additional bead and UIT of the transition between the additional bead and the weld metal;
e) preliminary deposition of the additional bead and UIT at the outer toes of the bead;
f) additional bead deposition after making of a weld. UIT at the outer toes of the bead.

7.5 Effective operating stress deconcentration radius is formed at the weld toe by UIT differs from deconcentration radius formed by any other technique.

The difference is that the effective value of deconcentration radius after UIT is defined by the geometry of the surface generated by the transfer of residual compressive stresses equal to yield strength into the area of elastic compressive stresses. This radius is at minimum 3 times greater than the deconcentration radius at the UIT treated surface (see Fig. 16).

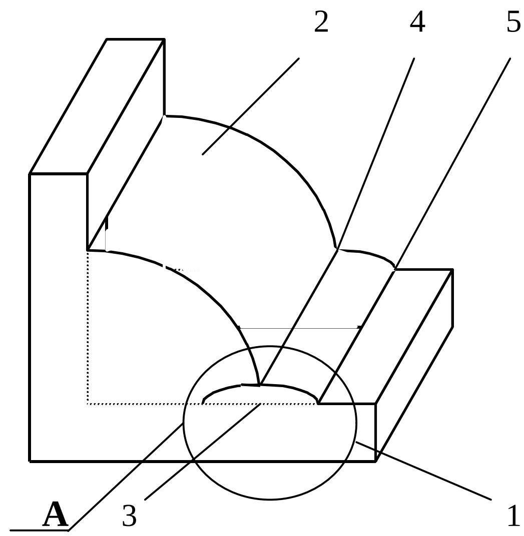
7.6 UIT type is selected in accordance with the following Table depending on the assembly class and the flank angle:

Assembly class as per clause 6	**Symbol of UIT variation**	
	Flank angle θ<60”	Flank angle θ>60”
1	d) and f) variations	e) and f) variations
2	b) variations	e) and f) variations

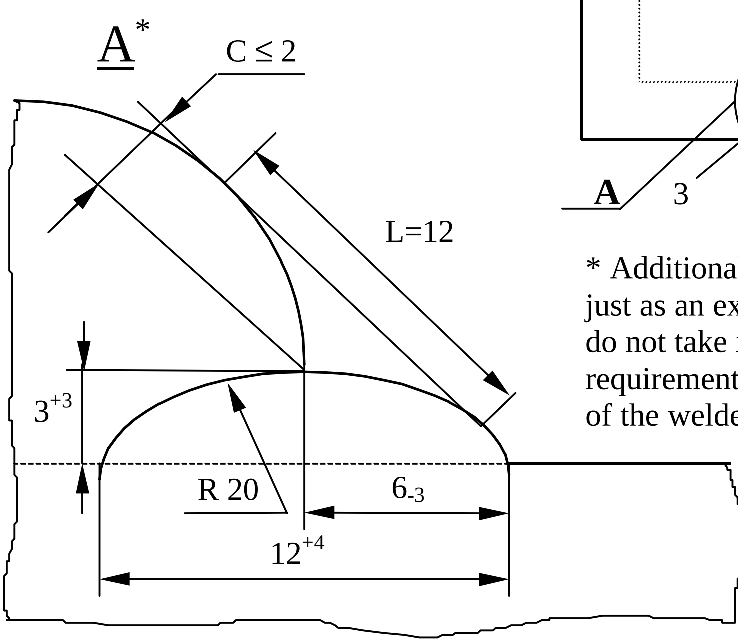
UIT variation shown in Fig. 12c is auxiliary and best to be used if UIT is applied at pre-melted parts of welds.

7.7 Additional bead geometry should correspond to Fig. 13.

Additional bead is made using welding parameters and electrode grade identical to those for making of the weld.



1 base metal;
2 weld metal;
3 additional bead;
4 fusion line between the additional bead and the weld metal;
5 fusion line between the additional bead and the base metal;

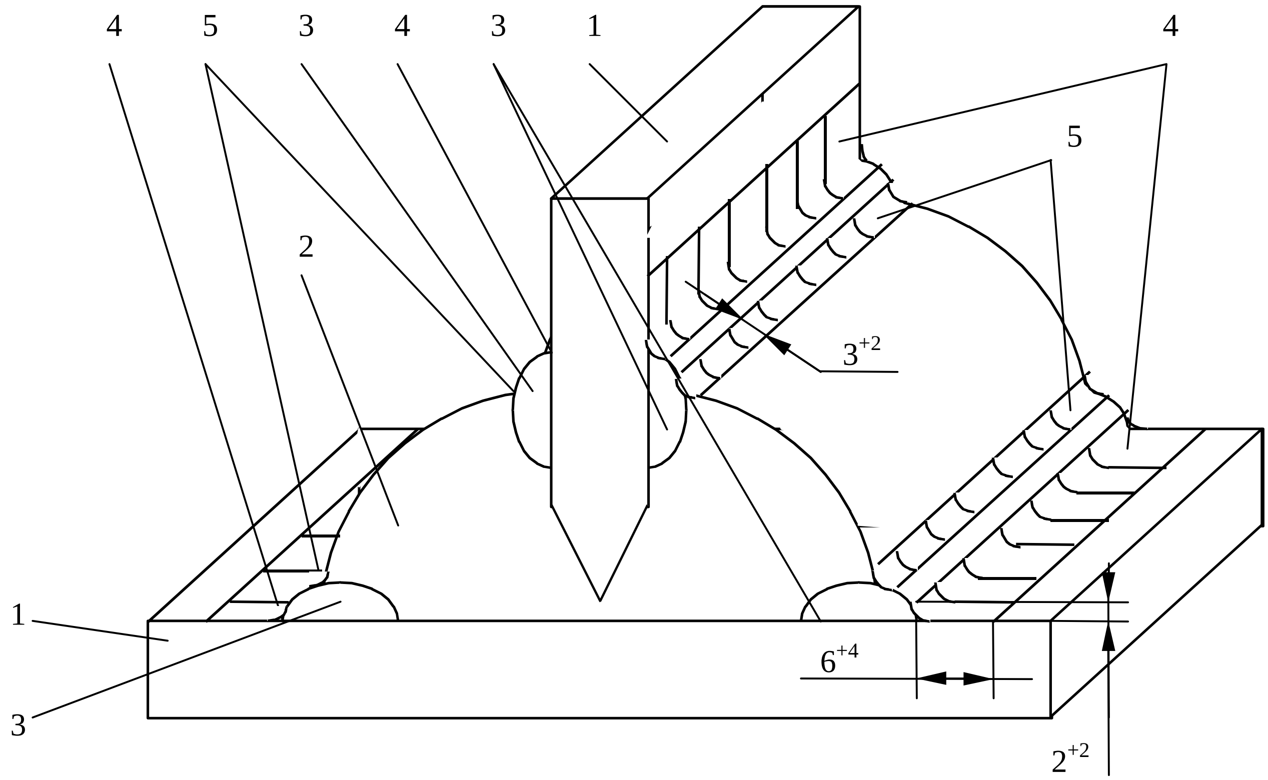


* Additional bead dimensions are indicated just as an example for UIT application and do not take into account all possible requirements for the structural arrangement of the welded joint.

L gauge length
Ñ depth of bead space

Fig. 13 Joint form with preliminary deposition of additional bead

7.8 UIT of T-joint subjected to extreme conditions is shown in Fig. 14.



1 base metal
2 weld metal
3 additional bead
4 UIT treated transition between the additional bead and the base metal
5 UIT treated transition between the additional bead and the weld metal

Fig. 14 UIT of T joint subjected to unfavorable conditions

7.9 UIT parameters for steel are selected in the following ranges:

excitation frequency	27 kHz
oscillation amplitude	30 - 40 micron
indenter diameter	2-5 mm
treatment speed (tool travel)	18-90 m/h

In the process of treatment the manual ultrasonic tool is located at right angles to the treated surface and pressed against the surface with an axial force of 20-40 N (2-4 kg). This force, as a rule, is produced by tool weight. UIT is used with translational or reciprocal movement of the tool along the weld toe until specified geometry of the treatment area is formed.

Techniques and tooling should ensure access for indenters to the weld toe. With sharp transition in the area of the weld toe, the indenters 1-2 mm in diameter are usable to have access to the weld toe (or indenters 3 mm in diameter with taper sharpening 1 2 mm).

7.10 Practical requirements for UIT application

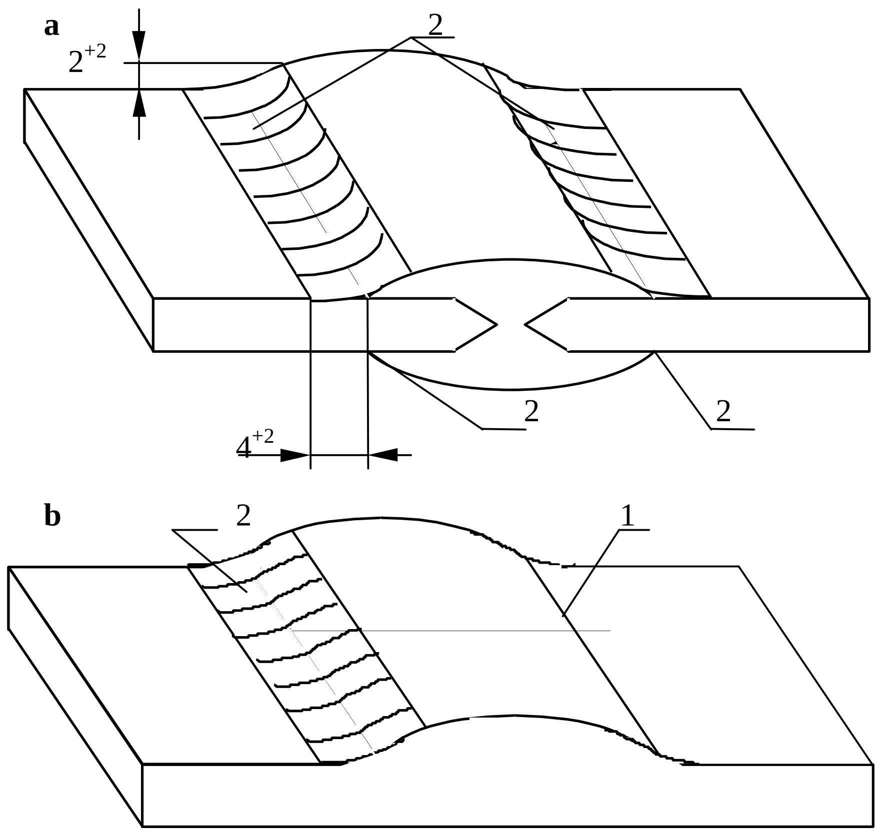
7.10.1 Welding of field joints with UIT application should be performed in accordance with previously designed procedures stipulating the sequence, process, technique and parameters of welding, build-up sequence, sequence and parameters of UIT.

7.10.2 UIT parameters for field welds are set with regard to the joint type, welding position, and welding process. Preliminary deposition of additional beads is added to the process as needed.

7.10.3 With UIT application in the technology of assembly and welding of structures, it is possible to eliminate or reduce preliminary angular change for joints to compensate welding deformations affecting final sizes and shape of the structure. In order to fully compensate welding deformations UIT parameters are specified in work production plan and checked after welding of initial sections.

7.10.4 Prior to field welding and UIT of structures, as-welded and UIT treated check joints are made to define the mechanical properties of the welded joint, penetration, residual stresses and deformations and assess the efficiency of UIT.

7.10.5 According to operating standards when welding control joints, the base metal, welding consumables, welding and UIT parameters adopted for a given structure should be used. Specimens are tested in accordance with operating standards. Sample joints treated by UIT are also used to make "UIT quality standards (Fig. 15). Strength, plasticity, toughness and hardness of weld metal and heat-affected zone therewith should conform to requirements of operating standards.



a) UIT treated butt joint
b) UIT quality standard for butt joint

1 as welded weld toe
2 weld toe after UIT

Fig. 15 UIT of butt joint and UIT quality standard

7.10.6 The groove is formed at the weld toe during UIT of welded joints (Fig. 16).

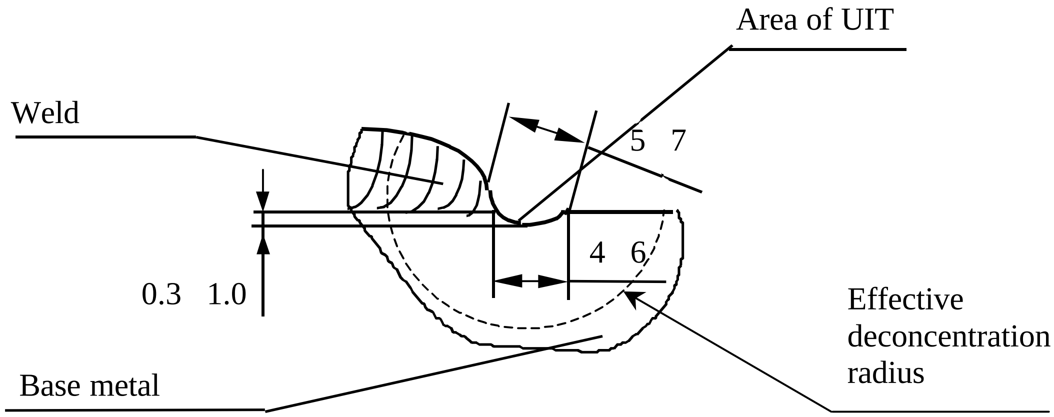


Fig. 16 Recommended groove profile after UIT, specifically for medium strength steel welded joints

7.10.7 During assembly with UIT of the most critical welded joints, it is recommended that the samples for mechanical tests be made and treated by UIT.

7.10.8 When making multi pass welds, UIT should be applied after each pass. Removing of slag is used after each pass. For this purpose, UIT tool is desirable for use.

7.10.9 Specially trained operators, after study of this guide, as well as design and operating manuals for UIT equipment and tools, are allowed to perform UIT.

7.10.10 UIT quality control is carried out as per requirements stipulated in the design documentation and this document. Surface quality in the UIT area and groove profile should comply with quality standards.

Conclusion

This Guide is the first version of the document defining the parameters, criteria and variations of UIT application in production and assembly of welded structures. This document may be supplemented and refined with consideration for the results of certification, research and experience of UIT practical applications in actual structures.

References

1. E.S. Statnikov. Applications of Operational Ultrasonic Impact Treatment (UIT) Technologies in Production of Welded Joints. IIW Doc. XIII-1667-97.
2. Yu.F. Kudryavtsev, V.I. Trufiakov, P.P. Mikheev, E.S. Statnikov. Increasing the Fatigue Strength of Welded Joints in Cyclic Compression. IIW Doc. XIII-1569-94.
3. J.J. Janosch, H. Koneczny, S. Debiez, E.S. Statnikov, V.I. Trufiakov, P.P. Mikheev. Improvement of Fatigue Strength in Welded Joint (in HSS and Aluminium Alloy) by Ultrasonic Hammer Peening. IIW Doc. XIII-1594-95.
4. E.S. Statnikov, L. Kelner J. Baker, H. Croft, V.I. Dvoretski, V.O. Muktepavel. Repair of Fatigue Cracks. IIW Doc. XIII-WG5-18-98.
5. E.S. Statnikov, V.I. Trufiakov, P.P. Mikheev and Yu.F. Kudryavtsev. Specification for weld toe improvement by ultrasonic impact treatment. IIW Doc. XIII-1617-96.
6. V.I. Trufiakov, E.S. Statnikov, P.P. Mikheev and A.Z. Kuzmenko. The efficiency of Ultrasonic Impact Treatment for improving the fatigue strength of welded joints. IIW Doc. XIII-1745-98.
7. P.J. Haagensen, E.S. Statnikov and L. Lopez-Martinez. Introductory fatigue tests on welded joints in high strength steel and aluminium improved by various methods including Ultrasonic Impact Treatment (UIT). IIW Doc. XIII-1748-98.