IIW Recommendations on Post Weld Improvement of Steel and Aluminium Structures

P. J. Haagensen and S J. Maddox

XIII-1815-00

Revised 4 July, 2001
CONTENTS

1. INTRODUCTION ................................................................................................................. 1

2. SCOPE .......................................................................................................................... 1
   2.1 Materials ............................................................................................................ 1
   2.2 Environment and loading ................................................................................ 1
   2.3 Types of welded joints ..................................................................................... 2

SECTION 1 MODIFICATION OF WELD TOE GEOMETRY ................................... 3
PRINCIPLE ................................................................................................................... 3

3. BURR GRINDING ............................................................................................................. 3
   3.1 Introduction ....................................................................................................... 3
   3.2 Equipment ........................................................................................................ 3
   3.3 Operator and inspector training ...................................................................... 3
   3.4 Safety aspects .................................................................................................. 4
   3.5 Weld preparation ............................................................................................. 4
   3.6 Procedure ......................................................................................................... 4
   3.6.1 Two stage grinding ...................................................................................... 7
   3.7 Corrosion protection ....................................................................................... 8
   3.8 Inspection and quality control ....................................................................... 8
   3.9 Documentation ............................................................................................... 8
   3.10 Fatigue strength of joints improved by grinding ............................................. 9

4. TIG DRESSING ........................................................................................................ 11
   4.1 Scope ............................................................................................................... 11
   4.2 Equipment ..................................................................................................... 11
   4.3 Weld preparation ............................................................................................ 12
   4.4 Dressing conditions and procedure ............................................................... 12
      4.4.1 Tungsten electrode .................................................................................... 12
      4.4.2 Shielding gas ............................................................................................ 12
      4.4.3 Preheat ....................................................................................................... 13
      4.4.4 Dressing parameters ............................................................................... 13
      4.4.5 Position of TIG torch and dressing zone .................................................. 13
      4.4.6 Arc stop and restart ................................................................................ 15
   4.5 Operator and inspector training ....................................................................... 16
   4.6 Remedial dressing ........................................................................................... 16
   4.7 Corrosion protection ....................................................................................... 16
   4.7 Inspection ........................................................................................................ 16
   4.8 Documentation ................................................................................................. 16
   4.9 Fatigue strength of joints improved by TIG dressing ...................................... 16
SECTION 2 INTRODUCTION OF COMPREHENSIVE RESIDUAL STRESSES

PRINCIPLE .................................................................................................................18

5. HAMMER PEENING
5.1 Introduction .............................................................................................................18
5.2 Equipment ...............................................................................................................18
5.3 Operator training ......................................................................................................19
5.4 Weld preparation .....................................................................................................19
5.5 Safety aspects .........................................................................................................19
5.6 Procedure ...............................................................................................................20
5.7 Inspection and quality control .................................................................................21
5.8 Documentation .......................................................................................................21
5.9 Fatigue strength of joints improved by hammer peening .......................................21

6. NEEDLE PEENING ..................................................................................................23
6.1 Introduction .............................................................................................................23
6.2 Equipment ...............................................................................................................23
6.3 Procedure ...............................................................................................................23
6.4 Operator and inspector training ..............................................................................24
6.5 Safety aspects .........................................................................................................24
6.6 Quality control and documentation .........................................................................24
6.8 Fatigue strength of joints improved by needle peening ..........................................25

6. REFERENCES ..........................................................................................................27

APPENDIX A IIW interlaboratory ..............................................................................28
APPENDIX B Production data sheets ...........................................................................29
- Grinding
- TIG dressing
- Hammer peening
1. INTRODUCTION

Weld improvement methods have been investigated in many test programs and have in most cases been found to give substantial increases in fatigue strength. However, there are large variations in the actual improvements achieved, and the results obtained by various methods are not always ranked in a consistent manner. One explanation for the observed variations is the lack of standardization of the optimum method of application, but variations in the material, type of loading and type of test specimens may also have influenced the results. The effectiveness of the treatment also depends heavily on the skill of the operator. In order to improve the reproducibility of the methods, and to produce guidance for the degree of improvement that could be expected when using the methods in actual practice, an inter-laboratory test program was undertaken by IIW in 1995. The participating organizations in the IIW round robin program are listed in Appendix 1. The program, in which 13 testing laboratories in 10 countries participated, involved the three commonly used methods: burr grinding, TIG dressing and hammer peening. This program has contributed to a better understanding of the reasons for the large scatter that is sometimes observed in fatigue tests of improved welds, and has provided a basis for a higher confidence in using the methods.

The recommendations in this document are derived mainly from earlier IIW publications [2-6]. They supplement the IIW fatigue design recommendations for as-welded joints [7] In addition to specifications for the practical use of the methods, guidance for inspection and quality control of these methods is also given. A successful implementation of these methods depends on adequate training of operators as well as inspectors. IIW Commission XIII is therefore committed to provide training aids and issue guidance for educating, training and certifying operators and inspectors.

The improvement techniques described in these recommendations are intended for use under the following circumstances:

a) Increasing the fatigue strength of new structures.

b) For repair or upgrading of existing structures.

Claiming a higher S-N curve as a result of using of improvement methods for new structures is obviously possible only in the applicable design code, or with the approval of the purchaser or the appropriate certifying authority.

2. SCOPE

2.1 Materials.
The recommendations apply to any arc welded steel or aluminum structure that is subjected to fatigue loading. Due to lack of experimental data for extra high strength steels the fatigue strength (or S-N) curves apply to structural steel grades up to a maximum specified yield strength of 900 MPa, and for aluminum alloys commonly used in welded structures, primarily the 5000 and 6000 series alloys.

2.2 Environment and loading.
The application of improvement techniques is limited to structures operating at temperatures below the creep range. Although some of the improvement methods will increase the fatigue lives of structures operating under freely corroding conditions, no guidance is given on the improvement that can be expected.
The recommendations do not apply to low cycle fatigue conditions where the nominal stress range $\Delta \sigma > \sigma_{YS}$, $\sigma_{YS}$ being the yield stress of the material. For peening techniques special restrictions are imposed, regarding applied peak loads and stress ratios, see Chapter 5.

2.3 Types of welded joints.
The recommendations apply to the improvement of welded planar joints or welded hollow section connections with plate thickness from 6 to 150 mm for steel, 4 to 50 mm for aluminium, or as specified for each improvement method.
The improvement methods covered in this document are applied to the weld toe. Thus, they are intended to increase the fatigue lives of the weld treated from the viewpoint of potential fatigue failure from the weld toe. Some examples of relevant weld details are show in Fig. 2.1.

Therefore, the possibility of a failure starting at some other location must always be considered. For instance, if the failure origin is merely shifted from the weld toe to the root there may be little scope for a significant improvement. It is emphasized that fatigue cracking from the root is governed by different design curves so any toe treatment cannot be expected to provide any improvement in the general case. Examples of details in which root cracking might occur are shown in Fig. 2.2.
SECTION 1

MODIFICATION OF WELD TOE GEOMETRY

PRINCIPLE

The weld toe is a primary source of fatigue cracking because of the severity of the stress concentration it produces. Apart from a relatively sharp transition from the plate surface to the weld, dependent on the weld profile, the stress concentration effect is enhanced by the presence of minute crack-like flaws, extending to depths (below any undercut) of a few tenths of a millimeter. Fatigue cracks readily initiate at these flaws. The primary aim of the improvement techniques that modify the weld toe geometry is to remove or reduce the size of these flaws and thus extend the crack initiation part of the fatigue life. A secondary aim is to reduce the local stress concentration due to the weld profile by achieving a smooth blend at the transition between the plate and the weld face.

3. BURR GRINDING

3.1 Introduction

The primary aim of the grinding is to remove or reduce size of the weld toe flaws from which fatigue cracks propagate. At the same time, it aims to reduce the local stress concentration effect of the weld profile by smoothly blending the transition between the plate and the weld face.

3.2 Equipment

A high speed pneumatic, hydraulic or electric grinder with rotational speed from 15 000 to 40 000 rpm is required.

A pressure from 5 to 7 bars for air-driven grinders is recommended. The tool bit is normally a tungsten carbide burr (or rotating file) with a hemispherical end (Fig. 3.1).

![Fig. 3.1. Pneumatic grinder and burrs.](image)

To avoid a notch effect due to small radius grooves the burr diameter should be scaled to the plate thickness (t) at the weld toe being ground. The diameter should be in the 10 to 25 mm range for application to welded joints with plate thickness from 10 to 50 mm. The resulting root radius of the groove should be no less than 0.25t.
3.3 Safety aspects
The high-speed grinding tool removes material at a high rate and is therefore capable of inflicting serious injuries to the operator or bystanders. The cutting operation itself produces hot, sharp cuttings and some noise. Therefore, heavy protective clothing together with leather gloves, safety glasses and ear protection are mandatory, see Fig. 3.2.

![Example of protective clothing.](image)

3.4 Weld preparation
The weld should be de-slagged and cleaned by wire brush before burr grinding.

3.5 Procedure
The quality of grinding depends on the skill of the operator, and each person has to experiment to find a technique that gives the desired result. Therefore only general advice is given below.

The burr grinding procedure is illustrated in Fig. 3.3. The burr is centered over the weld toe. The axis of the tool should be 45-60° to the main plate, and approximately 45° to the direction of travel. The grinder can be either pushed or pulled along the weld. Usually the former is more successful at establishing a straight groove of even depth. Grinding has to be extended to areas well outside the highest stress region at the ends of attachments, as indicated in Fig. 3.3b).

In general, grinding must extend to a depth of at least 0.5 mm below any visible undercut, see Fig 3.4. For plates up to 40 mm thick the maximum allowable depth is 7 % of the plate thickness, i.e. the maximum depth for a 20 mm plate is 1.4 mm. For thicker plates the maximum depth of grinding is 3 mm.

In large scale planar welded joints with plate thickness of the order of 42 mm and more, the high notch stresses in the toe region extend up on the weld face, and inter-bead toes may become crack initiation sites rather than the weld toe. This applies in particular to welds with low weld face angles. The treatment must therefore be applied to interbead toes within a region extending extending up the weld face by a distance (w) of at least half the leg length L, as illustrated in Fig. 3.4.
Fig. 3.4 The burr grinding technique, showing depth and width of groove in stressed plate.

A similar situation arises for welds in tubular joints, particularly those with large beta ratios ($\beta = \text{brace diameter}/\text{chord diameter}$), where the maximum stress is likely to occur on the weld face. Thus the whole weld face is highly stressed and must be ground as well as both weld toes. The situation is illustrated in Figure 3.5.
The weld toe geometry to be achieved by burr grinding is illustrated in Fig. 3.6. Note that an adequate throat thickness must be maintained and that the burr radius has to be scaled to the plate thickness and to the grinding depth.

Fig. 3.5 Stress distribution in a tubular joint (schematic), requiring grinding of the entire weld face and the weld toes in the brace and the chord.

Fig. 3.6 Details of burr ground weld toe geometry.
3.6.1 Two stage grinding.

In case of steep weld angle fillet or T butt welds in thick plates, for which large diameter burrs are required, it is often found that the burr has a tendency to ‘climb’ up the weld face, making it difficult to position the burr on the weld toe line. It is then recommended that grinding be carried out in two stages. First a small spherical tool, e.g. 6 mm diameter, is used to establish a groove of the correct depth and position, see Fig. 3.7. It proves to be easier to obtain the required quality of grinding in less time than using the large diameter tool alone.

The grinding rate depends on the weld geometry and material, but will be typically 50 to 100 mm per minute. The finished ground surface should be as smooth as possible, with no visible evidence of the original weld toe and any grinding marks at right angles to the weld toe line. Examples of appearances of correctly and incorrectly ground welds are shown in Fig. 3.8 a) and b), respectively.

---

**Fig. 3.7** Two stage grinding of large welds with steep weld angles

---

**Fig. 3.8** Appearances of burr ground butt welds; a) correctly, and b) incorrectly ground.
3.6 Corrosion protection

Corrosion pitting of the ground metal surface virtually eliminates the benefit of burr grinding. Therefore, the ground surface must be adequately protected. The protection may be of a temporary nature, as would be the case for a part of an offshore structure which would eventually be submerged and protected by a cathodic protection system. In other cases permanent protection must be provided by other means, e.g. a paint system.

3.7 Operator and inspector training

Some skill is required to perform burr grinding according to specifications and a training programme should be implemented for inexperienced operators. This should include a demonstration of the appearance of an adequately ground well as well as a demonstration of unacceptable welds and an explanation of the factors that influence the result. Actual grinding of at least 2 meters of weld, combined with periodic inspection and evaluation, is recommended.

3.8 Inspection and quality control

The inspection procedure must include a check on the weld toe radius, the depth of grinding, and confirmation that the weld toe has been removed completely. A depth gauge similar to the one used for measuring weld toe undercut (see Fig.3.9(a)) may be used, although the accuracy is low. Alternatively, or a go - no go type of gauge such as shown in Fig. 3.9b), may be more suitable. Visual examination under a bright light should be made to ensure that all traces of the original weld toe have disappeared. The ground surface of the groove should be inspected to make sure there are no deep scratches in the length direction, i.e. all grinding marks should be normal to the weld. A low power magnifying glass of approximately x5 is suitable for this work.

Fig. 3.9 Gauges for checking depth of groove.

3.9 Documentation.

A cast of the weld made using a silicone rubber of the type used by dentists is useful for documentation and for measuring the local geometry at the weld toe.
Data pertaining to the procedure should be recorded for the purpose of and quality control and quality assurance. The data are also useful for the purpose of correlating fatigue performance with burr grinding conditions when fatigue testing is performed. An example of a suitable data sheet, similar to the data sheets used for welding procedure specification (WPS), is reproduced in Appendix B.

3.10 Fatigue strength of joints improved by grinding.

The benefit of weld toe grinding for steel can be claimed only for details in FAT 90 Class or lower in the IIW notation for S-N curves. This limitation is due to the fact that the higher classes include non-welded details, details whose lives are not governed by weld toe failure or the welds that have been already been improved, e.g. by grinding the weld flush with the surface. For IIW FAT 90 Class or lower details the benefit of burr grinding corresponds to an increase in allowable stress range by a factor of 1.5, corresponding to a factor of 3.4 on life. In addition, it can be assumed that the constant amplitude fatigue limit corresponds to an endurance of $2 \times 10^6$. The maximum class is FAT 100, as shown in Fig. 3.10.

In cases where the structural stress (hot spot stress) approach is used, the improvement factor needs to be derived for an equivalent detail using its fatigue class based on nominal stress in conjunction with the limits specified above.

For aluminium welds, the same factors on the design S-N curves may be assumed. The highest detail class for which an improvement can claimed is FAT 40, and the highest S-N curve that can be claimed is FAT 45, as shown in Fig. 3.11.
Fig. 3.11. Benefit and limitation of improvement for burr ground aluminium weldments, S-N curves from IIW Fatigue Design Recommendations [7].
4. **TIG DRESSING**

4.1 **Introduction**

The aim of TIG dressing is to remove the weld toe flaws by re-melting the material at the weld toe. It also aims to reduce the local stress concentration effect of the local weld toe profile by providing a smooth transition between the plate and the weld face.

The present specifications are not applicable to connections with main plate thickness less than 4 mm for aluminium and 6 mm for steel.

4.2 **Equipment**

A standard TIG welding machine is used. Argon is normally used as shielding gas. Additions of helium is beneficial since this gives a larger pool of melted metal due to a higher heat input.

Typical conditions and range of dressing parameters used in reported tests are shown in Table 4.1. Typical manual TIG dressing equipment is shown in Fig. 4.1.

**Table 6.1** Typical TIG dressing conditions for steel.

<table>
<thead>
<tr>
<th>Shielding gas</th>
<th>Argon or argon+helium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas flow rate</td>
<td>7 - 12 liter/min</td>
</tr>
<tr>
<td>Nozzle diameter</td>
<td>10 - 14 mm</td>
</tr>
<tr>
<td>Preheat¹</td>
<td>50 - 200 °C</td>
</tr>
<tr>
<td>Electrode diameter</td>
<td>3 to 4 mm</td>
</tr>
<tr>
<td>Voltage, V</td>
<td>12 - 17 volts</td>
</tr>
<tr>
<td>Current, A</td>
<td>160 - 250 amperes</td>
</tr>
<tr>
<td>Dressing speed, S</td>
<td>80 - 160 mm/min</td>
</tr>
<tr>
<td>Heat input, HI²</td>
<td>1.0 - 2.5 kJ/mm</td>
</tr>
</tbody>
</table>

¹) Dependent on steel type and plate thickness.

²) Heat input is calculated from $\text{HI} = \frac{60 \times V \times A}{1000 \times S}$ (kJ/mm)

Fig. 4.1 TIG dressing equipment and partly dressed weld.
4.3 Weld preparation
TIG dressing is sensitive to most types of common weld contaminants such as mill scale, rust, oil and paint. The weld and adjacent plate should be thoroughly de-slagged and wire brushed. If necessary light grinding should be used to obtain a clean surface. Insufficient cleaning tends to result in the formation of gas pores that can have a strongly detrimental effect on fatigue performance. The problem of porosity is particularly important in TIG dressed aluminium welds.

4.4 Dressing conditions and procedure

4.4.1 Tungsten electrode
The shape of the arc depends on the shape and condition of the electrode tip. If the tip is contaminated or rounded by wear (oxidation) the arc becomes concentrated, so that the remelted zone narrows with an unfavorable effect on the bead shape. It is also difficult to start the arc and keep it stable. These problems can be avoided by regrinding the tip or replacing the electrode. Acceptable and unacceptable electrode tips are show in Fig. 4.2.

4.4.2 Shielding gas
If the gas flow rate is low or strong draughts disturb the gas shield the arc becomes unstable and defects such as surface pores are formed, or the electrode and bead oxidize. An adequate gas supply rate depends on many factors, including gas cup size, welding conditions and welding location (presence of draughts). An optimum flow rate should therefore be determined by trial dressing.

![Fig. 4.2 Electrodes for TIG torch; a) unused tip, c) contaminated electrode used on oxidized plate. After Millington [4].](image)
4.4.3 Preheat (steel only)
The heat input during TIG dressing is normally less than that used for welding the joint. Therefore, as a general rule the minimum preheat temperature to be used should be equal to that specified in the welding procedure. The exception to this is welds produced by the flux cored arc welding (FCAW) process due to a high hydrogen content. If TIG dressing is carried out just after welding, a higher preheat temperature must then be chosen to avoid cracking of the weld metal. However, some time after welding is completed the hydrogen content is less and the risk for weld metal cracking is reduced, and the preheat temperature can be reduced. In this case the preheat temperature for TIG dressing of FCAW joints may therefore be chosen on the basis of the preheat temperature that would be used for MMA welding. For steels with a carbon content in excess of 0.12 weight % the possible formation of hard zones in the heat affected zone should be considered. In such cases a second tempering TIG pass on the weld metal should be considered (8).

4.5.4 Dressing parameters
The objective of TIG dressing is to obtain a smooth transition from the plate to the weld bead. Dressing conditions may vary with the welding position, but as a general rule a high heat input should be used since this normally gives a low hardness in the heat affected zone (HAZ). Additionally, a high heat input also allows higher dressing speeds. An excessive heat input caused by a combination of high current and a low travel speed usually produces undercuts or a substandard bead profile. Suitable dressing conditions for the horizontal downhand position are shown in Fig. 4.3

![Fig. 4.3 TIG dressing conditions for steel (Millington4).](image)

4.4.5 Position of TIG torch and dressing zone
For an optimum result the remelted zone has to be positioned carefully with respect to the original weld toe. Normally the best result is obtained when the arc centre is located a small distance away from the weld toe, as indicated in Fig. 4.4a). Also shown in Fig. 4.4a) is a slight sideways tilt of the torch from the perpendicular position to obtain a favorable bead profile. In addition, the small backward tilt shown in Fig. 4.4b) may help to maintain an adequate gas shield.
If the arc is positioned too close to the weld bead it may result in the formation of a new toe as shown in Fig. 4.5b) and c). In general the electrode should be directed more towards the parent plate for steeper weld profiles, whereas for flatter beads the electrode should be positioned closer to the weld toe. If bead shapes similar to those shown in Figs. 4.5b) and c) are obtained, remedial treatment should be considered, see Sect. 4.6. A remelted weld toe as shown in Fig. 4.5a) represents an optimum shape with respect to fatigue. An example of a satisfactory treated weld profile is shown in Fig. 4.6.
4.4.6 Arc stopping and restarting

Arc starting and stopping may create craters or unfavorable bead profiles. This can be avoided by starting the arc about 6 mm behind the stop position as indicated in Fig. 4.7a). Alternatively the arc may be started on the bead and moved to the toe, Fig. 4.7b). The stop can also be made on the bead, Fig. 4.7c). The methods illustrated in Fig. 4.7a) and c) may be combined as shown in Fig 4.7d). Craters may also be avoided by changing the direction of welding, see Fig 4.7e). The welder should try various stop/restart techniques and choose one that gives a favorable bead shape.

Fig. 4.7 TIG dressing stop and restart techniques (After Millington [4])
4.5 Operator and inspector training
The quality of TIG dressing depends on an optimum combination of dressing parameters and the manual skills of the operator. The optimum dressing conditions are related to the individual characteristics of the welding equipment. The optimum shape of the dressed profile also depends to some extent on the shape of the initial bead profile. For this reason it is recommended that a trial programme is set up to familiarize the welder with the technique and develop optimum dressing conditions. The trials should include dressing with different heat inputs and torch positions. Arc starting and stopping techniques should also be practiced, see Section 4.6. After completing the training programme the operator should treat at least 1m of similar weld before starting production treatment.

4.6 Remedial dressing
If the TIG-dressed weld does not satisfy the inspection criterion with respect to weld shape, a new dressing run may be performed. If necessary a weaving technique may be tried or filler material could be used. The ease of repeating TIG dressing is one of the advantages of this method.

4.7 Corrosion protection
The benefit of TIG dressing is reduced if the surface is degraded by corrosion. Therefore, for maximum benefit, the TIG dressed surface must be be adequately protected against possible corrosion. The protection may be of a temporary nature, as would be the case for a part of an offshore structure that would eventually be submerged and protected by a cathodic protection system. In other cases permanent protection must be provided by other means, e.g. a paint system.

4.8 Inspection
The dressed weld should have a smooth transition from the plate to the weld face, with a minimum toe radius of 3 mm, in accordance with Figs. 4.5 and 4.6. The weld should be checked for complete treatment along the entire length of the part treated.

4.9 Documentation.
Data pertaining to the procedure should be recorded for the purpose of and quality control and quality assurance. The data are also useful for correlating fatigue performance with TIG dressing conditions when fatigue testing is performed. An example of a data sheets for TIG dressing, similar to that used for welding procedure specification (WPS), are reproduced in Appendix B.

4.10 Fatigue strength of joints improved by TIG dressing.
The benefit of TIG dressing for steel can be claimed only for details in FAT 90 Class or lower in the IIW notation for S-N curves. This limitation is due to the fact that the higher classes include non-welded details, details whose lives are not governed by weld toe failure or the welds that have been already improved, e.g. by grinding the weld flush with the surface.

For IIW FAT 90 Class or lower details the benefit results in an increase in allowable stress range by a factor of 1.5, corresponding to a factor of 3.4 on life. The maximum class attainable is FAT 100.
In cases where the structural stress (hot spot stress) approach is used, the improvement factor needs to be derived for an equivalent detail using its fatigue class based on nominal stress in conjunction with the limits specified above.

For aluminium welds the highest detail class for which an improvement can claimed is FAT 40, and the highest S-N curve that can be claimed is FAT 45, as shown in Fig. 4.9. Otherwise the enhancement factors on fatigue strength are the same as those for steel.
SECTION 2

INTRODUCTION OF COMPRESSIVE RESIDUAL STRESSES

PRINCIPLE

The other main approach to improving in the fatigue lives of welded joints that are most likely to fail from the weld toe is to introduce compressive residual stresses in the weld toe region. These have the effect of ‘clamping’ the weld toe in compression, with the result that an applied tensile stress must first overcome the residual stress before it becomes damaging. Thus, the applied stress is less damaging. Using the techniques described in this specification, compressive residual stresses are induced by mechanical plastic deformation of the weld toe region. Residual stresses then arise as a result of the constraint imposed by the surrounding elastic material.

An important practical limitation on the use of improvement techniques that rely on the presence of compressive residual stresses is that their fatigue lives are strongly dependent on applied mean stress. In particular, the benefit decreases as the maximum applied stress approaches tensile yield, disappearing altogether at stresses above yield. Thus, in general, the techniques are not suitable for structures operating at applied stress ratios of more than 0.5 or maximum applied stresses above around 80% yield. Note that the occasional application of high stresses, in tension or compression, can also be detrimental in terms of relaxing the compressive residual stress.

5. HAMMER PEENING

5.1 Introduction

In hammer peening, compressive residual stresses are induced by repeatedly hammering the weld toe region with a blunt-nosed chisel. The following specification is not applicable to connections with main plate thickness less than 4 mm for steel and 8 mm for aluminium.

5.2 Equipment

A pneumatic or hydraulic hammer is commonly used. A suitable pneumatic hammer gun has a 15 to 30 mm diameter piston, operates at an air pressure of 5 to 7 bars and delivers 25 to 100 Hz. Impact energy is typically in the range 5 to 15 Joules. The weight of the gun is from about 1.5 to 3.5 kg. Most research investigations of hammer peening have made use of the above types of hammer gun, both of which are primarily intended for use as chipping hammers. However, riveting guns have recently been found to be even better suited for peening because they are lighter and better vibration-dampened. These features will increase operator comfort and ease of use which in turn should improve control over the peening operation, and hence consistency and reliability of the resulting treatment. A riveting gun used successfully for hammer peening is shown in Fig. 5.1.

Hardened steel tool bits with approximately hemispherical tips, diameters between 6 and 18 mm, and length typically 100 to 200 mm are used. Such tools are not generally available as standard equipment but can be produced relatively simply by grinding the tips of standard chisels.
5.3 **Operator** and inspector training

Hammer peening is carried out manually. Some skill is required, and therefore the operator should receive appropriate training including a demonstration of successfully treated welds as well as unacceptable treatment. Some trial treatments, over at least 1 m of weld should be carried out before attempting to treat the actual component.

5.4 **Weld preparation**

The weld cap and adjacent parent material shall be fully de-slagged and wire brushed or ground to remove all traces of oxide, scale, spatter and other foreign material.

5.5 **Safety aspects**

Hammer peening, even using modern silenced hammers, is a noisy operation and it is essential that the operator and others working in the vicinity should use ear protection. Normal protective clothing for working in a fabrication shop is adequate, but it should include a face mask or goggles. Vibration from peening equipment may cause physical discomfort or harm, and the operator should not perform peening for extended periods of time. Vibration damping gloves may help to alleviate this problem.

5.6 **Procedure**

The aim in hammer peening is to plastically deform the material at the weld toe to introduce beneficial compressive residual stresses.

Effective treatment requires reasonably accurate positioning of the tip of the tool over the weld toe so that metal on each side (both weld metal and parent plate) is deformed. This will normally be achieved by supporting the hammer firmly and keeping the peening tool tip in close contact with the weld toe as it is moved along the weld. The hammer should be held at about 45º to the plate surface and approximately perpendicular to the direction of travel, as shown in Fig. 5.2, although in practice there will be a tendency to slope slightly as the tip of the tool tries to run ahead of the operator.

The resulting groove must be smooth and free from obvious individual indentations, as illustrated in Fig. 5.3. The travel speed will depend to some extent on access and hammer peening position, but also on the equipment used. A hammer gun which is heavy and vibrates will cause the tool to jump along the weld, missing some areas. Repeated peening, usually four passes, is then needed to achieve full coverage and a smooth surface. Lighter, vibration-damped hammer guns facilitate slower travel speeds, and hence more thorough treatment per pass. A travel speed of 50 to 100 mm/min, similar to typical welding speeds, should be aimed for when the required depth is achieved in one pass.
The diameter of the tool tip influences the resulting appearance of the hammer peened surface. In general, the smaller the diameter, the greater the likelihood that the actual weld toe itself will be peened and eventually disappear. Peening with a large diameter tool (greater than 12 mm) does not usually reach the weld toe but instead deforms material either side of it. Although in general the desired effect will be achieved with fewer passes using a large diameter tool, the presence of the original weld toe is a disadvantage from the viewpoint of inspection. In particular, it is not obvious that the toe has been correctly treated (i.e. left in a state of compressive residual stress) and remnant traces of weld toe confuse in-service inspection, since it is difficult to distinguish between them and fatigue cracks. Thus, the use of a small diameter tool, or a combination of small and larger diameter tools, with the aim of deforming the actual weld toe offers the best compromise. Inspection would then ensure that all traces of the original weld toe had disappeared.

In circumstances in which the treated weld will be subjected to a high-tensile mean stress in service, hammer peening will offer little or no benefit. When practicable, this problem can be overcome by performing the peening operation while the weld is under tensile load. For maximum benefit, this should be at least as high as the minimum stress to be experienced in service.
5.7 Inspection and quality control

In general, it is not possible to verify that hammer peening has been performed correctly by visual inspection alone. Important features like coverage and surface finish can only be described qualitatively, while the extent of plastic deformation, which reflects the level of compressive residual stress induced, is too small for reliable measurement in most practical circumstances. An important step is therefore to establish an acceptable hammer peening procedure and then to ensure that it is followed.

The hammer peening procedure should be established by performing trials on the material to be treated, preferably containing a representative weld, in the same position as the welded joint to be treated. The toe should be peened and examined after each pass. The treatment can be assumed to be complete when there is a uniform indentation along the weld toe with a smooth surface finish, and all traces of the original weld toe have disappeared. As a guide, but not a requirement, the indentation depth below the original plate surface is likely to be of the order of 0.5 mm. The minimum depth is 0.3 mm. The indentation depth will not normally exceed 1 mm. Treatment of the actual weld detail should be verified by visual inspection. This will check hammer peening position, coverage and general uniformity by comparing the hammer peened area with a reference sample or photograph.

5.8 Documentation.

Data pertaining to the procedure should be recorded for the purpose of quality control and quality assurance. The data are also useful for correlating fatigue performance with hammer peening conditions when fatigue testing is performed. An example of production data sheet, similar to those used for welding procedure specification (WPS), is reproduced in Appendix A. Test pieces used in trials should be retained for later review.

5.9 Fatigue strength of joints improved by hammer peening.

Benefit of hammer peening of steel components can only be claimed for details in design Class FAT 90 or lower in the IIW notation for S-N curves, as shown in Fig. 5.4. This limitation is due to the fact that the higher classes include non-welded details, details whose lives are not governed by weld toe failure or the welds that have been already been improved, e.g. by grinding the weld flush with the surface.

For the IIW FAT 90 or lower classes for steel the benefit consists of an upgrading to Category 125 with a constant amplitude fatigue limit at $2 \times 10^6$ cycles, Fig. 5.4.

For aluminium welded components improved by hammer peening the FAT 56 curve is allowed for detail categories FAT 40 and lower, see Fig. 5.5.

Fatigue tests on large-scale structures indicate lower benefit from hammer peening than for small–scale specimens. However, the main basis for the above recommendations is data obtained from small-scale welded specimens. Therefore, it is recommended that for structures with plate thickness larger than 25 mm the benefit for hammer peening is assumed to be the same as for Grinding and TIG dressing, i.e. a factor of 1.5 on allowable stress range, limited to FAT 100 for steel, and FAT 45 for aluminium weldments.

Due to the sensitivity of hammer peened welded joints to applied mean stress, the higher S-N curves can only be used under the following circumstances:
- The maximum nominal compressive stress in the load spectrum is lower than $0.25 \times \sigma_y$.
- When the applied stress ratio $R < 0$, the S-N curve is used in conjunction with full stress range.
- When the applied stress ratio $R \geq 0$ (all stresses in tension) the S-N curve is used in conjunction with the maximum stress instead of the full stress range.

![Diagram](image)

**Fig. 5.4** Benefit and limitation of improvement for hammer peened steel weldments, S-N curves from IIW Fatigue Design Recommendations [7].

![Diagram](image)

**Fig. 5.5.** Benefit and limitation of improvement for hammer peened aluminium weldments, S-N curves from IIW Fatigue Design Recommendations [7].
In cases where the structural stress (hot spot stress) approach is used, the improvement factor needs to be derived for an equivalent detail using its fatigue class based on nominal stress in conjunction with the limits specified above.

6. NEEDLE PEENING

6.1 Introduction

In needle peening, compressive residual stresses are induced by repeatedly hammering the weld toe region with a bundle of round-tipped rods. Compared with hammer peening, it is generally more suitable when large areas need to be treated. e.g. welds in tubular joints. As in the case of hammer peening, the following specification is restricted to plate thicknesses of 4mm for steel and 8mm for aluminium.

6.2 Equipment

A standard needle gun of the type used for removing slag and scale is suitable for needle peening, Fig. 6.1a). However, where necessary it is useful to modify the chuck, as shown in Fig. 6.1b), to align the steel rods in a rectangular pattern rather than a circular one; this will facilitate the treatment of weld toes. Additionally the ends of the rods should be rounded, see Fig 6.1 b).

Fig. 6.1 Needle peening equipment.

6.3 Procedure

The aim in needle peening is to plastically deform the material at the weld toe to induce beneficial compressive residual stresses. Effective treatment requires reasonably accurate positioning of the bundle of needles over the weld toe so that metal on each side (weld metal and
parent plate) is deformed. Needle peening can be performed immediately after welding, while the weld is still hot, if required. The toe should be needle peened four times to achieve optimum benefit and adequate coverage. The resulting surface should be bright in appearance and contain a uniform distribution of small indentations.

The operation is carried out with the tool held at approximately 45° to the plate surface with the ends of the needles in contact with the weld toe, as illustrated in Fig. 6.1. Needle peening is done with a sufficient force on the tool to prevent unsteady movement and enable even peening. It is not necessary for the operator to exert undue force in this operation, particularly using a lightweight gun, and therefore operation in the overhead position can be carried out with relative ease. The rate of treatment is approximately 800 mm per minute.

It is important to achieve full coverage of the weld region to be treated. To obtain this peening is carried out until the area is free for untreated spots. The time to do this is noted. 100% coverage of needle marks is checked visually, using a x5 to x10 magnifying glass. Then the area is treated again for the same length of time, to achieve what is termed 200% coverage.

The location of the needle peened area, extent of coverage and general uniformity of appearance should be checked visually with the aid of a low power magnifying glass (x5-10). A useful contrast between the needle peened surface and the surrounding untreated surfaces can be achieved if the surfaces are first strained with toolmakers blue, the dye being removed by the needle peening operation. Light grinding the weld toe region before needle peening, to obtain a dull surface finish, will also facilitate visual examination of peened areas.

### 6.4 Operator and inspector training

Some skill is required to perform needle peening and a training programme should be implemented for inexperienced operators. This should include a demonstration of the appearance of an adequately treated weld as well as a demonstration of unacceptable welds and an explanation of the factors that influence the result. If available, reference samples that have been correctly needle peened should be used for comparison. The training programme should include actual peening of at least 1 meter of weld, combined with periodic inspection and evaluation. Inspectors should be similarly trained to understand the requirements for correctly treated welds.

### 6.5 Safety aspects

Needle peening, even using modern silenced hammers, is a noisy operation and it is essential that the operator and others working in the vicinity should use ear protection. Normal protective clothing for working in a fabrication shop is adequate, but it should include a face mask or goggles. Vibration from peening equipment may cause physical discomfort or harm, and the operator should not perform peening for extended periods of time. Vibration damping gloves may help alleviate this problem.

### 6.6 Quality control and documentation

A suitable record of the needle peening operation is photographs taken at intervals along the peened area, using identification markings, similar to the documentation of weld quality by X-ray pictures. Care has to be taken to arrange the lighting source in such a way as to provide photographs that show any areas that inadvertently may have been untreated. After prolonged use, the tips of the
needles will revert back from the rounded shape introduced by grinding to being flat ended. At this time, the tips should be reground to produce a rounded shape.

6.7 Fatigue strength of joints improved by needle peening.

Benefit of needle peening of steel components can only be claimed for details in design Class FAT 90 or lower in the IIW notation for S-N curves. This limitation is due to the fact that the higher classes include non-welded details, details whose lives are not governed by weld toe failure or the welds that have been already been improved, e.g. by grinding the weld flush with the surface.

For IIW FAT 90 or lower classes for steel the benefit consists of an upgrading to Category 125 with a constant amplitude fatigue limit at $2 \times 10^6$ cycles, as shown in Fig. 6.2.

For welded aluminium components improved by needle peening the FAT 56 curve is allowed for detail categories FAT 40 and lower, Fig. 6.3.

Due to the sensitivity of hammer peened welded joints to applied mean stress, the higher S-N curves can only be used under the following circumstances:

- The maximum nominal compressive stress in the load spectrum is lower than $0.25\sigma_Y$.
- When the applied stress ratio $R < 0$, the S-N curve is used in conjunction with the full stress range.
- When the applied stress ratio $R \geq 0$ (all stresses in tension), the S-N curve is used in conjunction with the maximum stress instead of the full stress range.

![Fig. 6.2. Benefit and limitation of improvement and benefit for needle peened steel weldments, S-N curves from IIW Fatigue Design Recommendations [7].](image-url)
In cases where the structural stress (hot spot stress) approach is used, the improvement factor needs to be derived for an equivalent detail using its fatigue class based on nominal stress in conjunction with the limits specified above.

Fig. 6.3. Limitation of improvement and benefit for needle peened aluminium weldments, S-N curves from IIW Fatigue Design Recommendations [7].
7. REFERENCES

6. Haagensen, P. J. and Maddox, S J.” Specifications for Weld Toe Improvement by Burr Grinding, TIG Dressing and” IIW WG2 Doc.
# Appendix A

## IIW Round Robin Testing Program

### Participating laboratories

<table>
<thead>
<tr>
<th>Lab. ID</th>
<th>Short name</th>
<th>Organisation</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab 1</td>
<td>CETIM/IS</td>
<td>Centre Technique des Industries Mecaniques/Institut de Soudure (two labs shared testing)</td>
<td>France</td>
</tr>
<tr>
<td>Lab 2</td>
<td>SSAB</td>
<td>Swedish Steel AB</td>
<td>Sweden</td>
</tr>
<tr>
<td>Lab 3</td>
<td>NTNU</td>
<td>The Norwegian University of Science and Technology</td>
<td>Norway</td>
</tr>
<tr>
<td>Lab 4</td>
<td>TIT</td>
<td>Tokyo Institute of Technology</td>
<td>Japan</td>
</tr>
<tr>
<td>Lab 5</td>
<td>TWI</td>
<td>The Welding Institute</td>
<td>UK</td>
</tr>
<tr>
<td>Lab 6</td>
<td>CEMUL</td>
<td>Instituto Superior Technico, Lisbon</td>
<td>Portugal</td>
</tr>
<tr>
<td>Lab 7</td>
<td>LUT</td>
<td>Lappeenranta University of Technology</td>
<td>Finland</td>
</tr>
<tr>
<td>Lab 8</td>
<td>BAM</td>
<td>Bundesanstalt für Materialforschung und -prüfung</td>
<td>Germany</td>
</tr>
<tr>
<td>Lab 9</td>
<td>TUD</td>
<td>University of Delft</td>
<td>The Netherlands</td>
</tr>
<tr>
<td>Lab 10</td>
<td>TUB</td>
<td>Technical University of Braunschweig</td>
<td>Germany</td>
</tr>
<tr>
<td>Lab 11</td>
<td>PWI</td>
<td>Paton Welding Institute</td>
<td>Ukraine</td>
</tr>
</tbody>
</table>
Appendix B

Production data sheets for burr grinding, TIG dressing.
### PRODUCTION DATA SHEET

**for WELD TOE IMPROVEMENT by BURR GRINDING**

<table>
<thead>
<tr>
<th>WELDING SPECIFICATION</th>
<th>COMPONENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base material:</td>
<td>Type:</td>
</tr>
<tr>
<td>Filler material:</td>
<td>Identification:</td>
</tr>
<tr>
<td>Welding procedure No:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make and model:</td>
</tr>
<tr>
<td>Power:</td>
</tr>
<tr>
<td>Tip diameter:</td>
</tr>
<tr>
<td>Weight (with tool tip):</td>
</tr>
<tr>
<td>Rotation speed:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TREATMENT DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position:</td>
</tr>
<tr>
<td>Work angle, sideways:</td>
</tr>
<tr>
<td>Work angle, weld direction:</td>
</tr>
<tr>
<td>Travel speed:</td>
</tr>
<tr>
<td>Number of passes:</td>
</tr>
<tr>
<td>Length of treatment:</td>
</tr>
<tr>
<td>Time of treatment:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INSPECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ Visual</td>
</tr>
<tr>
<td>□ Photo</td>
</tr>
<tr>
<td>□ Geometry measurements</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operator:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OPERATOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience: 1. Hours: ________ 2. Length of weld treated: ________</td>
</tr>
<tr>
<td>Operator’s name:</td>
</tr>
</tbody>
</table>

### TOE GEOMETRY MEASUREMENTS

<table>
<thead>
<tr>
<th>Spacing of measurement points (mm):</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Max.</th>
<th>Min.</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toe radius (mm):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groove depth (mm):</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Measurements report: __________________