MAGNETIC FORCE ON THE WELDING ARC

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Key words: magnetic force, welding arc, deflection of the arc, arc blow, undercuts, triple-wire electrode

Abstract: The article states causes, effects and methods of preventing welding arc deflection in welding, surfacing and other processes involving welding arcs. The first part of the article gives a short survey of literature reporting on effects of various kinds of magnetic fields on the welding arc, on material transfer, and on the welding processes itself. Some fundamental theoretical principles of physics covering magnetic and electromagnetic fields, which affects the welding arc directly or indirectly, are described.

Then two main causes for arc blow effect are indicated. These are an electromagnetic field, which generates due to welding current flow, and permanent magnetic field, which generates in work pieces due to various reasons.

Two macro sections of surfacing welded with triple - wire electrode and with different voltage are shown, which effects on the arc blow.

Magnetne sile na varilnem obloku

Kjučne besede: magnetna sila, varilni oblok, odklanjanje obloka, plesanje obloka, obrobne zajede, tržična elektroda

Izvleček: Članek obravnava vzroke, posledice in metode za preprečitev odklanjanja obloka pri varjenju, navarjanju in pri drugih akttivnostih z varilnim oblokom. V prvem delu članka je podan kratek pregled literature, ki poroča o različnih vplivih magnetne sile na varilni oblok, prehajanje materiala in na celoten process. Opisani so nekateri osnovni teoretični oziroma fizikalni principi magnetnih in elektromagnetnih polj, ki direktno ali indirektno vplivajo na varilni oblok. Prikazana sta dva najznačilnejša pihalna učinka (odklanjanje obloka) varilnega obloka. To sta elektromagnetno polje, ki se generira zaradi prevajanja električnega toka in permanentno magnetno polje, ki zaradi različnih vzrokov nastane v varjencih.

Prikazana sta dva maro obrusa navarov, varjena s tržično elektrodo z različno obločno napetostjo, kar vpliva na odklanjaje varilnih oblokov.

1 Introduction

In the practice of arc welding, weld defects such as weld surface irregularities and undercuts occur. Welders most often neither know the causes of their appearance nor methods for preventing these defects. These defects are very often caused by arc deflection which is due to effect of magnetic and electromagnetic forces. Electromagnetic forces are produced by welding current flow, while magnetic forces are due to inhomogeneous magnetic field in the work piece, a welded structure or even in the filler material.

The welding arc is a process of electric discharge in a gas through which an electric current flow. Carriers of electric current in the welding arc are electrons and ion, also called plasma. Each current conductor is surrounded by an electromagnetic field. Owing to changes in conductor diameter, also electromagnetic field density varies. By arc welding electromagnetic field is very often inhomogeneous, which results in electromagnetic effects.

2 A short literature survey on research in the field of magnetic forces on the welding arc

In the literature of the last decade it is hard to find an article reporting on magnetic field effects on the welding arc. An exception seems to be reference /1/, in which a general survey of arc deflection due to magnetic field effects and cures to this can be found.

Investigations on magnetic field influence on the welding arc, on material transfer, and on weld shape began in the sixties, but they were most intensive in the seventies and the eighties /2-6/.

In all the references stated, the main purpose was to investigate the feasibility of arc deflection, its restriction, and its control during welding. Fewer reports are dealing with prevention of influences exerted by the magnetic field, which was generated by welding current flow through the electrode, the arc and the work piece.

Between the electric current and magnetic field there are certain effects which are comprised in the term "Lorentz force". This force, which is a vectorial product of electric current and magnetic flux density, can deflect the arc or move it along a certain area /7,8/. In this way the arc can be controlled.

In literature reports on investigations on the influence of a longitudinal magnetic field on the melting rate and the welding process /9,16/. Owing to the outside magnetic field effects electric resistance in the arc increases, a lower current is flowing through the arc while wire feed speed is kept constant. The melting rate can thus be increased by 50 % /10/.

Problems due to arc blow effect are not thoroughly investigated in the literature.

3 Some theoretical principles of physics

A magnetic field exists between poles of permanent magnets or around current-carrying wires. We can visualize it with the help of lines of force. In case of a straight current - carrying wire, the lines of force form concentric circles (Fig.1a). If the wires is wound in the form of a coil consisting of several loops, the lines of force get more concentrated and run through the coil.

In a relatively long coil, the lines of force are parallel to each other, which means that there is a homogeneous magnetic field in the coil (fig.1b). Magnetic field intensity can be measured by a magnetometer. It is dependent on electric current intensity flowing through the coil, on the number of loops, and on the coil length.

$$H = \frac{I \cdot N}{l} \qquad \left[\frac{A}{m}\right]$$

I [A] - current intensity

N [/] - number of loops

L [m] - coil length

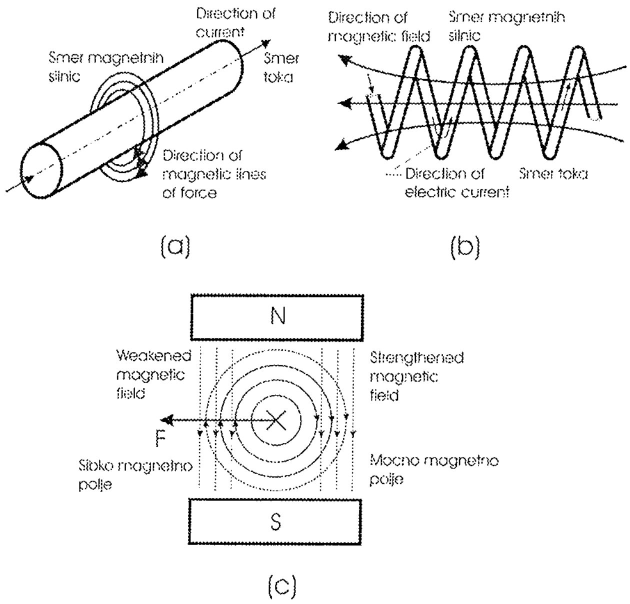

Figure 1: *Correlation between electric current and magnetic field;* ***a*** *- Magnetic field around a current-carrying wire,* ***b*** *- Magnetic field pattern in a relatively long coil carrying direct current;* ***c*** *- Direction of force, visualized by magnetic lines of force, is dependent on electric current.*

The magnetic field intensity in the middle of an infinite current - carrying wire is calculated by dividing electric current intensity with the wire diameter. The magnetic field intensity at a certain distance from the wire is calculated by dividing with "$2\pi r$", where "r" is the distance perpendicular to the wire.

Magnetic flux density is a vector of which the direction is a tangent to a magnetic line of force. It is defined at a point as a force F at that point which the homogeneous magnetic field exerts on a small length of wire that carries an electric current.

$$F = B \cdot I \cdot L \qquad \left[\frac{Vs \cdot A \cdot m}{m^2}\right] = \left[\frac{N}{m}\right]$$

B [T = Vs/m^2] - magnetic flux density

I [A] - current intensity

L [m] - conductor length

$$B = \mu \cdot H \qquad \left[\frac{Vs \cdot Am}{m^2 \cdot Vs}\right] = \left[\frac{Aa}{m}\right]$$

μ [Vs/Am] - permeability

It was already in 1845 that Faraday found out that an inhomogeneous magnetic field exerts a force on all the substance in the magnetic field in the direction of the field gradient. The magnetic force is thus exerted if the magnetic field is inhomogeneous.

Figure 3 shows a simple and well - known case, i.e. Principle of the effect of a magnetic force. The magnetic force is acting in the direction from a higher concentration of magnetic lines of force to their lower concentration.

In welding, the cross section through which electric current is flowing varies because the current flows not only through the welding wire, but also through a molten drop, the welding arc, the molten pool, and the work piece. Variations in the conduction cross section entail variations in current distribution density, and consequently in magnetic flux density, which means that the magnetic field is inhomogeneous. Another case in welding is when magnetic lines of force run through various media having specific magnetic permeability which causes a non-uniform distribution of magnetic lines of force, which generates magnetic forces.

4 What is magnetic arc blow and where does it arise

In all welding process in which electric arc or electron beam is used energy by the motion of electrically charged particles. Carriers of electric current in solid conducting materials are electrons, while in gaseous materials, i.e. arc, these are electrons and positively or negatively charged ions. During welding, the cross section, the shape, and the physical condition of the conductor vary; consequently the direction of action of the electromagnetic force varies as well. The welding arc possesses a magnetic field of its own, which is unsymmetrical due to the difference in magnetic permeability, which causes arc deflection.

Such cases are shown in Figure 2. In the first case (Figure 2a), the electromagnetic force is deflecting the arc due to a stronger magnetic density at point "A". Magnetic flux density is dependent on welding parameters as well as on the location of fixation of welding cables. In both cases (Figures 2b and 2c), magnetic arc blow can be eliminated by setting two or more welding cables at various location on the work piece so that the welding current flows from the arc through the work piece in various directions. Figure 2b shows the magnetic arc blow occurring, during welding, at the edge of the work piece. Magnetic flux density in the vicinity of the arc is asymmetrical due to various media, which induces an electromagnetic force which deflects the arc. In practice, this problem can be solved by inclining the electrode, by a choice of suitable welding parameters or by a special metal prolongation which makes magnetic flux easier and forms a symmetrical magnetic field round the arc.

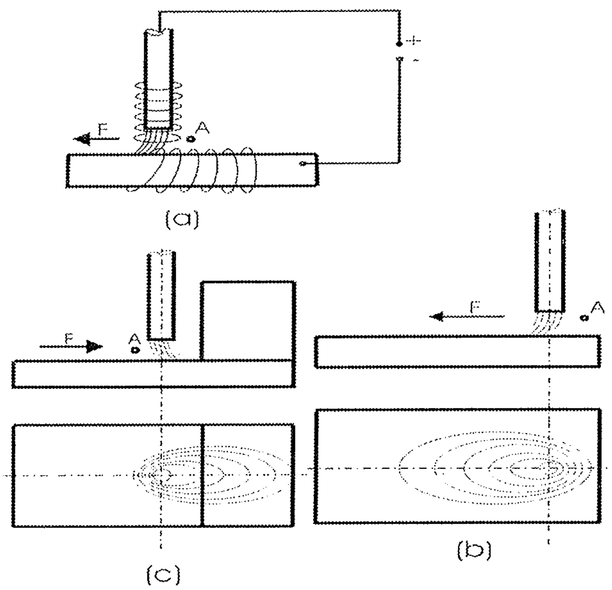

Figure 2: *Magnetic force on the arc welding;*
F *- Direction of the magnetic force,*
a *- Direction of arc deflection is dependent*
b *- on direction of welding current flow, Magnetic arc blow occurring during welding at the edge of workpiece,*
c *- Magnetic arc blow occurring during welding along the wall of metal plate.*

Magnetic arc blow occurs also during welding along the wall (Figure 2c) or in the narrow gap in the groove. The magnitude of arc deflection is affected also by the shape of the weld groove, the level of the magnetization of individual work piece, and total magnetic field intensity which may increase by a factor 10 if two work pieces are brought closer together. Fig. 3 shows influences of the groove shape on the distribution of magnetic density or magnetic lines of force in the weld groove.

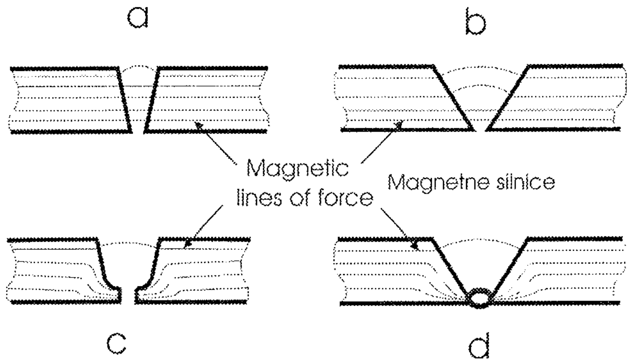

Figure 3: *Influence of groove shape on magnetic field intensity which is proportional to density of magnetic lines of force in the weld groove.*

It can be described as follows:

- Magnetic field intensity in the narrow gap is relatively strong, but distributed across the whole area of the groove.
- In the wider grove, the magnetic field is weaker than in the narrow one and concentrated in the weld root.
- In the U groove, magnetic field density is even higher and may be increased if two work pieces are brought closer together.
- The root pas having been welded, magnetic field density in the weld groove reduces.

Magnetic field density and magnitude of electrodynamic force which deflects the arc and causes undesired effects differ from one welding process to another. Practical experiences show that magnetic flux density of up to 2 mT does not induce magnetic arc blow. Magnetic flux densities of 2 mT up to 4 mT usually induce deflection, but for the majority of welding process, this is still acceptable and quality weld can be made. At higher magnetic flux densities, however, certain measures should be taken.

It should be stressed once again, however, that the magnetic field intensity measured at the tip of the work piece may rise by up to 10 times if the workpieces are joined together.

When several work pieces are joined, not only magnetic field density, but also other magnetic field properties, such as magnetic induction, permeability, remanence, coercive, and magnetostriction, changes as well.

5 Influence of the welding process on magnetic arc blow

Magnetic arc blow is different in different welding processes. Higher arc voltage causes electrons in the arc to travel faster and turn less in the magnetic field. Consequently arc deflection is weaker and the arc is more stable. The welding arc burning under higher pressure then atmospheric is more prone to deflection since electrons in the arc are slower. Arc deflection is stronger in TIG welding then in MAG/MIG welding or manual arc welding, because in TIG welding, arc voltage is usually lower.

It happens, however, very often that arc deflection causes difficulties in welding with multiple-wire electrode or in welding with several electrodes.

In welding with multiple-wire electrode, the wires are supplied from single power source, which means that in the wires different or the same direct currents may flow and welding parameters can not be changed for each individual wire. If the current is flowing through the wires paralelly in the same direction, the wires and the arcs attract each other (Figure 4), which may result in weld surface irregularities and undercuts /11/.

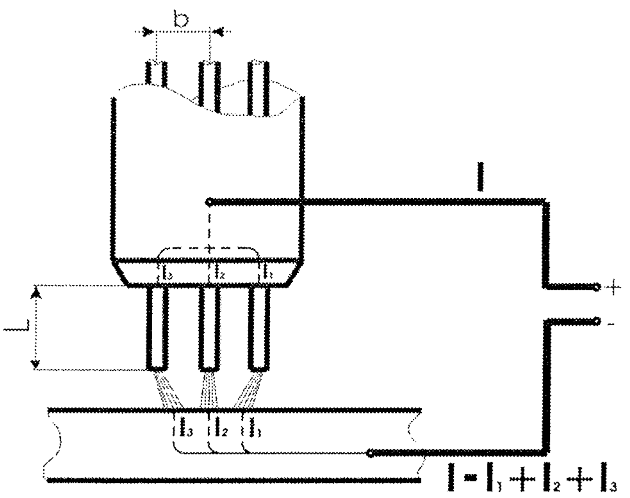

Figure 4: *Welding arcs attract each other in welding with multiple-wire electrode with direct current due to electromagnetic forces;* **L** *- wire extension length,* I_1, I_2, I_3 *- current intensity in the wires*

The choice of suitable welding parameters, wire-to-wire distance, wire extension length, and wire arrangement in the contact tip are, therefore, of utmost importance in welding with multiple-wire electrode /12,13,14/.

Figure 5 shows macrosections of two submerged-arc surfacing welded with triple-wire electrode, the wires being arranged in the direction transverse to the welding direction. In both cases, all welding parameters, with the exception of welding voltage, were kept constant. The wire used had a diameter of 2 mm, wire extension length was 28 mm, wire-to-wire distance 7 m, welding speed 30 cm/min, current intensity 195 A/wire and arc voltage 35 V in the first case (left) and 20 V in the second case (right). As stated, the only varying parameter was arc voltage. The figure and the welding parameters confirm the fact that the welding arc with lower voltage is more sensitive to magnetic arc blow because electrons in the arc are slower. Together with the arc (Figure 4), also droplets deflect from the ideal direction perpendicular to the work piece. They detach from the wires and travel in the direction of the arc. This affects the surfacing shape (Figure 5, right). In welding of the surfacing as shown in figure 4 (left), the welding parameters selected are ideal. High arc voltage creates stable arcs, there is no magnetic arc blow among them, therefore, the droplets detached travel from the wire to the weld in perpendicular direction. The weld shape is uniform and without undercuts.

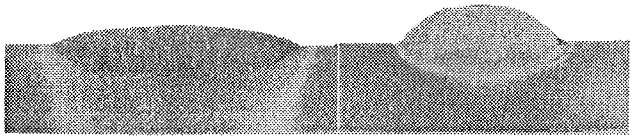

Figure 5: *Macrosections of submerged-arc surfacings welded with triple-wire electrode, wires being arranged in the direction transverse to welding direction. Welding parameters:* ***I*** *= 3 x 195 A,* d_0 *= 2 mm,* **L** *= 28 mm,* **b** *= 7 mm,* v_v *= 30 cm/min,* **U** *= 35 V -* ***left***, **U** *= 20 V -* ***right.***

In welding with several electrode heads, each wire is supplied from a separate power source and has separate driving and regulation systems. This means that different currents of different intensity and voltage may flow in individual wires. It is recommended to use in practical welding cases, as regards the first wire, direct current with low arc voltage and high current intensity. As regards the other wires, alternating current with a somewhat higher arc voltage and somewhat lower current intensity should be used. The alternating currents in the wires should be phase-delayed in order to prevent mutual electromagnetic influence.

The electromagnetic force between two or more arcs in welding with several electrodes supplied with alternating current can be calculated according to the following equation:

$$F_i = \frac{\mu_o \cdot I_i^2}{2 \cdot \pi \cdot b \cdot \cos\Phi_{ij} \cdot \cos\Phi_{jj}}$$

F_i - electromagnetic force exerted on i^{th} arc
μ_o - magnetic permeability in the air
I_i - effective value of welding current in the i^{th} arc
Φ_{ij}, Φ_{jj}- angle of inclination of electrode (Figure 6)
b - distance between arcs

6 Causes of magnetic field generated in workpieces

We have been mainly talking about magnetic arc blow which occurs due to an electromagnetic field. But arc deflection and magnetic arc blow may occur also due to a magnetic field existing in workpieces or in a welded structure as a whole.

It is well known that only ferromagnetic materials, such as iron, cobalt, nickel, and their alloys, can be magnetised. Some materials are more easy to magnetise and more difficult to demagnetise. It is usual to distinguish between magnetically hard and soft materials. Magnetically soft materials are relatively easy to magnetise, but only to certain degree. Magnetically hard materials are more difficult to magnetise, but they remain magnetised.

For ferromagnetic materials, it can be stated that there is a correlation between magnetic hardness and metallurgical hardness.

There are different causes of magnetisation of workpiece. Ferromagnetic workpieces can get magnetised from the earth's magnetic field or other local magnets, such as various magnetic clamps used in mechanical or other treatments of the workpiece, devices for magnetic inspection, high-frequency welding units, and welding cables running along the workpieces.

Various electrical connection cables, tack welds and other means of tacking can cause local magnetisation or intensity magnetic field in the welding structure.

It has already been mentioned (Figure 2) that the welding current (particularly direct current) may provoke arc blow, which is often the case and causes difficulties in welding.

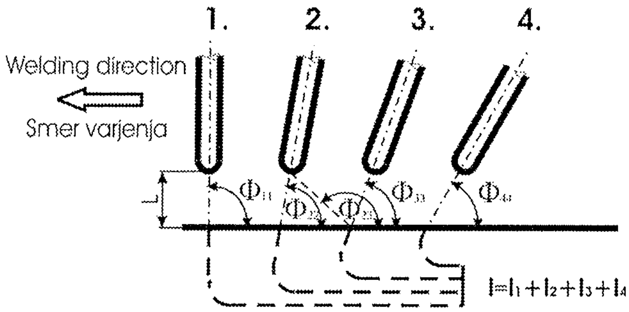

Figure 6: *Schematic representation of a system for welding with four electrodes, including data required for calculation of electromagnetic force;* Φ_{ij}, Φ_{jj} *- angle of inclination of electrode,* I_1, I_2, I_3, I_4 *- current intensity in the wires*

7 Measures for reducing problems caused by magnetic arc blow

In practice, several more or less efficient methods for reduction or even elimination of the influence of the magnetic field on arc deflection during arc welding is known. For reduction of magnetic field concentration in the root area of the weld preparation, special leather bags filled with iron powder can be used. They permit a uniform distribution of magnetic lines of force across the weld groove. For demagnetisation of larger structures, strong power sources producing current intensities over 20 kA can be used. These devices are very expensive, but they do not always guarantee success.

Success can be achieved in a simple and cost-effective way by current-carrying welding cables wrapped around the weld preparation. But first it is necessary to establish magnetic field intensity and its direction in the weld groove.

In the magnetic field intensity in the weld groove does not exceed 4 mT, the effect of magnetic arc blow can be prevented by the selection of appropriate welding parameters. This can be achieved by welding with larger electrode - wire diameters and by suitable weld preparation (Figure 3) so that the arc burns in a proper distance from the magnetic field.

Stronger magnetic fields can be eliminated, as already mentioned, by wrapping current-carrying welding cables around the work piece.

It is known, magnetic field intensity and its direction are depended upon the number of loops, current intensity, and current direction, coil length, and kind of the material. Therefore, this operation should be carried out as carefully as possible in order not to produce an opposite effect.

For demagnetisation of a 2 mm thickness, 50 Hz alternating current can be used. For demagnetisation of greater thickness's, direct current should be used.

In welding of larger structures, such as pipes and hollow sections, the structures as a whole can not be demagnetised, but local demagnetisation around the weld groove should be achieved.

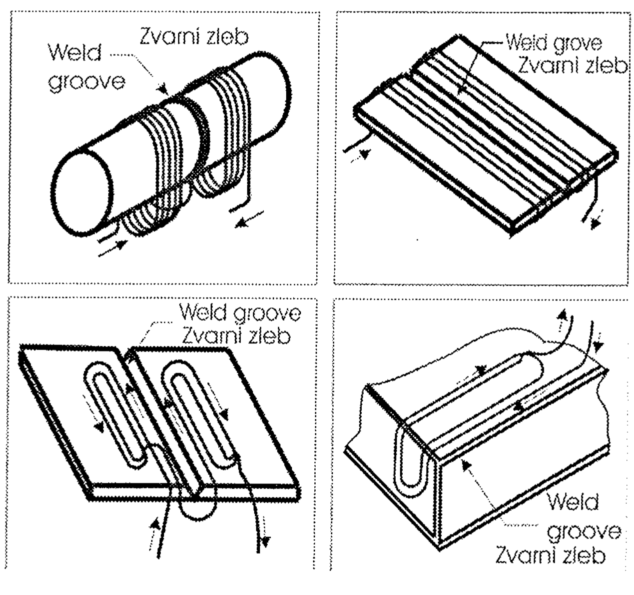

Figure 7: *Some alternative variants of electric cable arrangement to demagnetise weld groove, i.e. welded joint.*

The magnetic field intensity in the parent metal and in the vicinity of the weld groove can be reduced by using an auxiliary welding equipment which supplies direct current which can be set to values lower than that of the welding current, i.e. even down to 10 A. The electric cables should be wrapped around the workpiece in the direction parallel to the weld groove as shown in Figure 7. The number of turns depends on the magnetic field intensity existing in the weld groove. It is recommended to wrap up ten turns of cable around the groove. The direction of electric current in the cable is also very important.

If the current does not flow in the correct direction, the magnetic field in the workpiece does not reduce, but increases. The direction of the current and the effect of demagnetisation can easily be established by a welding wire (if it is not austenitic) or more accurately by a measuring instrument.

With the correct selection of demagnetisation parameters, demagnetisation should be complete in 5 seconds.

Figure 8 shows a practical application of the demagnetisation method described. At the weld, that part of the root run is marked where the magnetic field was eliminated. Those parts where the magnetic field was not eliminated from the weld preparation are visible as well.

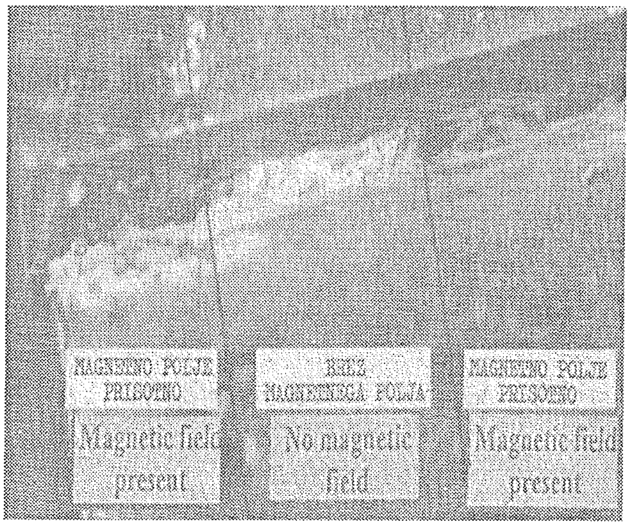

Figure 8: *Root run welded in the presence of magnetic field (left, right) and in its absence (centre).*

8 Conclusions

In the article, causes for generation of magnetic arc blow in arc welding are stated. There are usually two causes for arc deflection, i.e. magnetic arc blow, namely the electromagnetic field produced by the welding current and the magnetic field existing in one or more workpieces.

Magnetic arc blow causes weld defects, such as undercuts and weld surface irregularities. Magnetic arc blow should, therefore, be eliminated or its effect prevented. For this purpose, the article states several methods.

The generation of magnetic arc blow due to welding current can be prevented by application of several welding cables disposed, in an optimum manner, across the workpiece or with various metal prolongations which produce an electromagnetic field around the welding arc homogeneous as possible.

If an electromagnetic field is existing in the workpiece, prevention of magnetic arc blow generation is much more difficult because arc blow may arise all of a sudden, and demagnetisation of the workpiece is not easy. The article describes how the magnetic field in the workpiece or in the weld groove can be eliminated and secure favourable conditions for quality welding.

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