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Repair welding of elements of the sign ARBEIT MACHT FREI of the main gate to the former German Nazi concentration and extermination camp Auschwitz I

Editor's note

After the end of the Second World War the sign "ARBEIT MACHT FREI" on the gate to the former German Nazi concentration and extermination camp Auschwitz I became one of the most important symbols of German Nazi concentration camps, slave labour, inhumane conditions and mass genocide — the Holocaust.

Mieczysław Kościelniak (camp serial number 15261) "Work squads marching out to work", Poland, 1950, from the collection of the Auschwitz-Birkenau State Museum

Introduction

In the former German Nazi concentration and extermination camp Auschwitz I in 1940, a sign reading "ARBEIT MACHT FREI" (work makes one free) was put up over the main gate. The sign was made in the shop of the camp's locksmith under the management of Jan Liwacz (camp serial number 1010). At night, on 17/18 December 2009 the sign was stolen from the Auschwitz-Birkenau State Museum in Oświęcim. After recovering it, it turned out that during the theft the sign (5570 mm in length and 360 mm in height) sustained significant damage – it was cut into three parts, bent, the sections of the upper and lower pipes (ϕ 33x3 mm [1]) were twisted and deformed and one of the letters ("I" in the word FREI) fell off (Fig. 1).

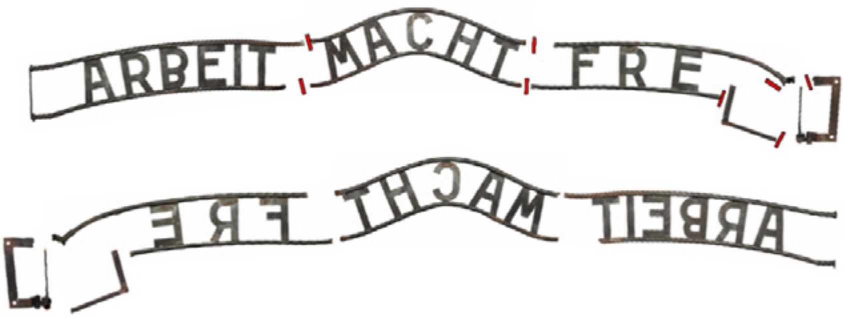

Fig. 1. Front and back of the sign damaged during the theft. Red colour marks spots where the sign was cut or where its elements were torn off [1]

After the sign had been recovered, its exceptional and symbolic significance helped to reach a decision on correcting the theft-related

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deformities, as they considerably distorted the primary reception of the sign. Afterwards, all the fragments were to be joined to form a whole sign again. Straightening and joining have an enormous effect on the legibility of the primary functions and meaning of the sign; therefore, the activities had to be preceded by a very thorough investigation. The fundamental assumption of the conservation was to protect all the components of the sign – pipes, letters, welds, and preserve the original paint coatings. At first, the conservators thoroughly documented the condition of the sign. In doing so they used visible light as well as ultraviolet and infrared photography. The sign was scanned in three dimensions. The tests also involved analysis of the chemical composition and hardness measurements of the material out of which the individual elements of the sign were made. Thanks to endoscopy and magnetic particle inspection it was possible to identify the slightest metal damage, invisible to the naked eye. Separate tests were carried out in relation to the protective coatings. All of these activities allowed the development of a programme of conservation [2].

According to the assumptions of the conservation programme, the connections of all the elements of the sign should be stable, durable, possibly invisible, and have no detrimental effect on the appearance of the sign. It was decided that the method employed to join the elements should be the same as that applied originally, i.e. welding. Such a method should ensure a relatively narrow heat affected zone, minimum porosity, and complete penetration of the pipe joints (due to changing loads of the sign put up on the gate). Other requirements included entirely crack-free joints and as little difference in the colour of the welds and the parent metal of the elements made of carbon steel.

The Conservation Section of the Auschwitz-Birkenau State Museum turned to Instytut Spawalnictwa with a request to conduct these works aimed at selecting a technology of repair welding the sign elements; the technology was to meet requirements formulated by the Conservation Section. The request also required technological supervision over the repair welding of the sign elements [5, 6]. The process and results of the conservation are presented below.

Parent metal of sign elements

The upper and lower seamed pipes of the historic sign are made of carbon steel having the chemical composition as presented in Table 1.

Carbon steel used in the production of the sign pipes is characterised by good metallur-

Table 1. Results of chemical analysis of pipe material [1] and carbon equivalent

Sign pipe	Contents of chemical elements [%]							Carbon equivalent Ce [%]
	C	Si	Mn	Cr	V	Ni	Cu	
upper	0.0585	0.0065	0.3255	0.006	0.002	0.008	0.0228	0.12
lower	0.0956	0.0065	0.4606	0.006	0.002	0.008	0.0203	0.18

Lower pipe – Al content: 0.025%; P content: 0.0218%; S content: 0.0468%.
Upper pipe – Al content: 0.025%; P content: 0.0268%; S content: 0.0661%.

Carbon equivalent: $C_e = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}, \%$

Table 2. Results of chemical analysis of material of pipes technological welding tests [5]

Test pipe	Contents of chemical elements [%]							Ce [%]
	C	Si	Mn	Cr	Mo	V	Ni	Cu	
upper	0.065	<0.010	0.29	0.095	0.019	<0.004	0.085	0.170	0.15
lower	0.098	<0.010	0.39	0.045	0.005	<0.004	0.015	0.042	0.18

gical weldability, confirmed by the chemical composition and related carbon equivalent. For this reason, welding of the steel does not require any special precautions aimed at preventing the formation of hardened structure in the heat affected zone.

On the basis of a low silicon content (Si<0.05%) it may be stated that the pipes were made of effervescing steel, deoxidized only with manganese and revealing a tendency for welded joints to develop porosity, attributable to a high oxygen content. Due to this observation, a welding technology and consumable (filler metal) ensuring possibly low porosity of joints should have been selected.

According to the chemical analysis carried out by the Conservation Section, the letters had also been made of effervescing steel, containing 0.02% Si; 0.063÷0.62% Mn; 0.01% Cr; 0.04÷0.05% Ni; 0.12÷0.17% Cu; 0.005% Al; 0.01% V; 99.1÷99.2% Fe [1]. The lack of data concerning the content of carbon makes it impossible to determine a carbon equivalent. Visual inspection of the welded joints between the letters and the pipes of the historic sign revealed no cracks in the joints and base metal. There were, however, some cracks caused by bending of the sign during the theft. As a result of the inspection, it was concluded that the steel of the letters was also characterised by good weldability.

This study, aimed at the selection of an appropriate welding technology, was greatly facilitated by six pipe sections found by the Conservation Section and provided to Instytut Spawalnictwa. Three of these sections (ϕ33.9 mm x 3.2 mm) came from a pipe used in a structure built in the camp, probably in 1940 (designated as 1), whereas the remaining three (ϕ33.9 mm x 3.2 mm) (designated as 2) came from another pipe which was probably used at a later date. The chemical composition of these pipes is presented in Table 2; it corresponds to unalloyed structural steel of general purpose S185 acc. to PN-EN 10025-2:2005 (equivalent of steel St0S acc. to PN-88/H-84020).

The mechanical properties of the material of the pipe designated as 2 were determined during a tensile test. The yield point R0.2 of the material put to the test, determined for three test pieces was 228.2 MPa; 250.6 MPa and 238.9 MPa, whereas tensile strength Rm amounted to 339.2 MPa; 362.4 MPa and 349.8 MPa respectively. The elongation A5 of the test pieces was 26.3%, 25.8% and 22.1%.

Determination of scope of repair welding works

The scope of the repair welding was determined on the basis of a visual inspection of the damaged sign prior to and following the straightening. Examples of the damage caused by the theft are presented in Figure 2 below.

The upper and lower pipes of the sign were bent, broken, torn off and deformed (Fig. 3÷11). The thickness of the pipe wall in broken spots was between 2.5 mm and 3.2 mm.

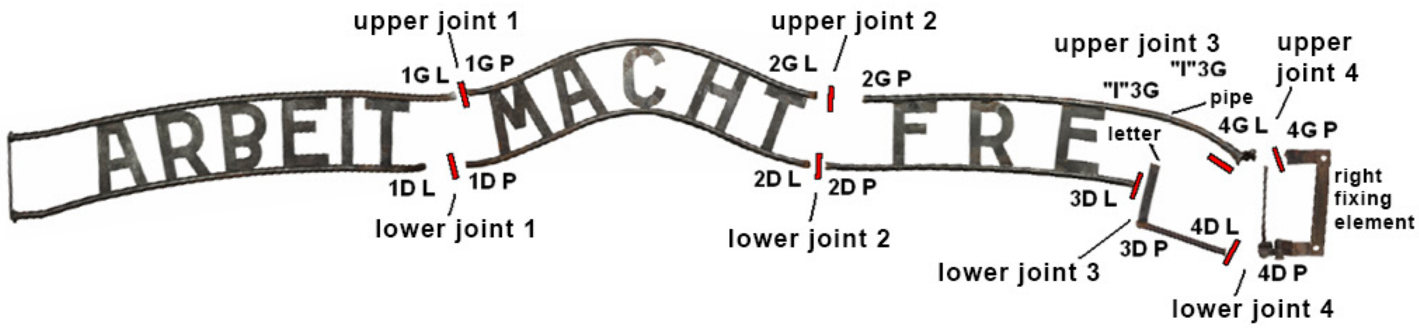


Fig. 2. Fragment of sign with designation of repair welded joints

Fig. 3. End of upper part (1GL acc. to 2) after word ARBEIT

Fig. 4. Broken end of upper pipe (1GP acc. to Fig. 2) before word MACHT

Fig. 5. Bent end of broken lower pipe (1DL acc. to Fig. 2) after word ARBEIT. Visible deformation of letter “T”

Fig. 6. End of the lower pipe (1DL acc. to Fig. 2) partially cut on along its circumference and then broken

Fig. 7. 120 mm-long crack of lower pipe on section 1DL acc. to Fig. 2

Fig. 8. Ends of upper and lower pipes (2GL and 2DL acc. to Fig. 2) after word MACHT. Visible bending of upper pipe at angle of approx. 90°

Fig. 9. End of partly cut and broken upper pipe (2GL acc. to Fig. 2) after words MACHT

Fig. 10. End of partly cut and broken upper pipe (2GP acc. to Fig. 2) before word FREI

Fig. 11. Broken and deformed lower pipe at weld joining pipe with letter ”I” in word FREI

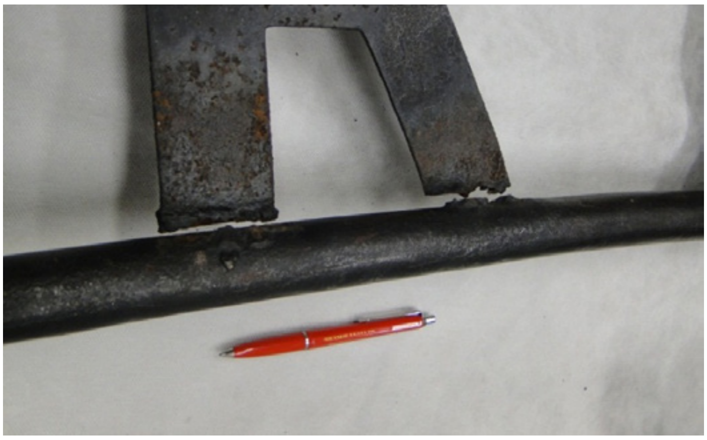


Fig. 12. Torn off welds joining letter ”R” with lower pipe in word FREI

Fig. 13. Crack (partly torn weld) on the length of 15 mm in weld on upper left side of letter ”E” in word FREI

Fig. 14. Weld torn off, located on the upper right side of the letter ”E” in word FREI (weld torn of on the length of 37.5 mm)

Damage was also caused to the welded joints between the letters and the pipes. During the visual inspection it was possible to notice cracks – welds partly or fully torn off on their whole length. Examples are presented in Figures 12÷15.

Fig. 15. Weld joining the letter ”I” with upper pipe in word FREI – letter broken off on the whole length of welded joint (part of weld remained on pipe)

It was also possible to observe cracks (Fig. 16) and material torn off along the fastening on the right side the sign.

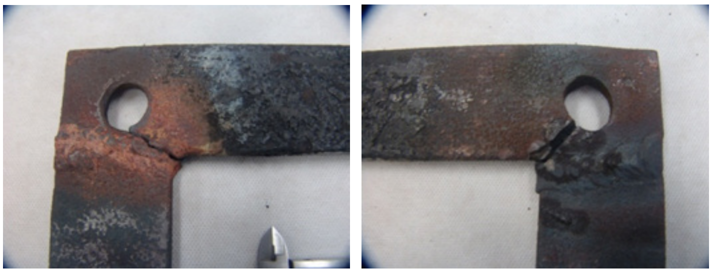


Fig. 16. Cracks in corners of right element fastening sign to pole – view from sign side

In order to eliminate the adverse effect of rust and protective varnish covering the sign on the quality of the welded joints after straightening, prior to welding the zone directly adjacent to the area of planned welding underwent sand-blast cleaning. After removing paint from the existing welds and the adjacent area, it was ascertained that some cracks visible on the surface of the straightened elements were only present in the layer of the paint and not in the metal beneath it. The visual inspection also revealed the presence of residual welding slag (i.e. slag formed by molten electrode covering) in the welds of the letters “B” (from the front side of the sign), “E” (from the front side of the sign), “I” (from the front and back side of the sign, from the bottom) in the word ARBEIT, “M” (from the front side, from the bottom of the sign, from the left side) and the letter “C” (from the front side, from the bottom of the sign), among others. On the basis of this inspection it was possible to ascertain that the welded joints were welded manually with covered electrodes. Removal of the paint revealed welding imperfections which had been formed during the original welding of the historic sign. These faults included a burn-through in the upper joint of the letter “A” in the word ARBEIT and a gas pore in the welded joint of the bottom left base of the letter “R” in the same word, from the front side of the sign.

On the basis the visual inspection of the sign, after its straightening by the artistic metalwork company EDEX-POL in Sułkowice and sand-blast cleaning of the zone directly adjacent to the area of the planned welding, a detailed list of the necessary repair welding was prepared. The scope of the work included the production of butt joints of the upper and lower pipes of the sign, welding the sign-fastening elements, as well as welding the fragments which had cracked and were torn off [6].

Tests of historic sign pipe after hot straightening

The damaged fragments of the sign underwent cold or hot straightening. According to information provided by the Conservation Section, in the case of hot straightening the elements were first heated up to a temperature of 830°C÷1050°C (orange colour of steel incandescence) and cooled quickly afterwards. Visual inspection did not reveal any cracks in the places adjacent to the area which had been heated.

Tests of the microstructure of the historic sign pipe were conducted using the damaged section of the lower pipe, adjacent to the letter “I” (3DP acc. to Fig. 2) in the word FREI. The section in question underwent hot straightening and next, on the basis of the type and size of the damage, was qualified for a removal and replacement by a 50 mm-long insert.

Before microstructural analysis the pipe material was tested for the contents of carbon, sulphur and phosphorus, which amounted to 0.038%, 0.052% and 0.069% respectively. The above results, along with the results cited according to the study [1], confirmed that the chemical composition of the pipe being tested corresponded to low-carbon unalloyed structural steel. For this reason, after hot straightening followed by cooling in water, the material of the pipe should be free from disadvantageous hardened structures. In order to verify the above statement it was necessary to carry out microscopic metallographic examination of the pipe material, revealing the presence of ferritic structure with numerous non-metallic inclusions. The material of the pipe after hot straightening and fast water cooling did not reveal any hardened structures. The hardness of the pipe material measured in the metallographic specimen was between 119 HV10 and 184 HV10. The microscopic examination and hardness measurements confirmed that post-straightening repair welding did not require any additional heat treatment.

Initial selection of method for welding the elements of the sign

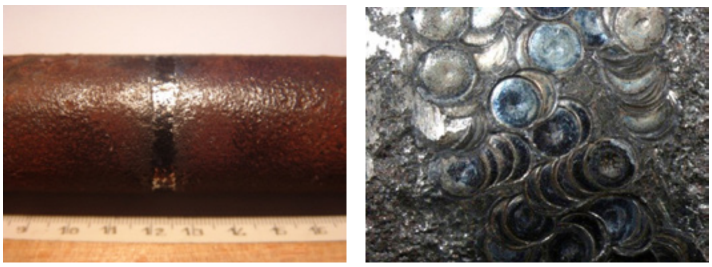
The initial selection of the welding method was based on the repair-related requirements enumerated above and took into consideration the arrangements made with the Conservation Section while preparing expertise and connected with the necessity to ensure a relatively narrow zone of welding-related heat effect on the material and paint cover of the pipe and a minimum weld reinforcement (aesthetical joint appearance). At this stage also the basic requirements concerning repair welding were specified.

The initial selection of the repair welding method was based on the assessment of pipe joints made by means of the following methods: oxy-acetylene welding (process 311), manual metal arc welding (process 111), semi-automatic MAG welding (process 135), TIG welding (process 141), plasma arc welding (process 15) and laser beam welding (process 52).

The assessment focused on the girth joints of pipes welded at Instytut Spawalnictwa using oxyacetylene welding, manual welding with covered electrodes, TIG welding and plasma arc welding as well as joints welded by outside companies (at the request of the Conservation Section) with the use of laser beam welding, MAG welding with solid wire electrode, TIG welding and combined welding i.e. a penetration layer and filling layers were made with TIG welding whereas the face layer was made with a laser beam. After analysis of these welding methods it was ascertained that the methods useful in the process of making pipe joints would be TIG welding, plasma arc welding, laser welding with backing, and a combined method i.e. penetration by means of TIG welding and the face layer using laser beam welding. The methods ensured good quality of the joints of the sign, including the pipe joints with complete penetration, minimum reinforcement and a relatively narrow heat affected zone. The torn off letters and the cracks in the welds joining the letters with the pipe could be repaired by means of plasma arc welding and TIG welding with a filler material, with fillet welds, the same as in the case of the original sign.

Test welding of pipes nos. 1 and 2 supported by tests of the quality of welded joints facilitated the selection of welding consumables ensuring relatively low porosity of welded joints made of effervescing steel. Radiographic tests revealed the quality level B of girth joints made with Castolin Eutectic-manufactured rods grade CastoTIG 45255, intended for welding of unalloyed steels and ensuring the yield point of weld deposit R0.2 > 385 MPa. The tensile strength of two test pieces of the joint from pipe no. 1 was 411.5 MPa and 382.9 MPa with the rupture occurring outside the weld. Positive results of radiographic and strength tests confirmed the usability of TIG welding, plasma arc welding and rods grade CastoTIG 45255W.

The tests also confirmed the possibility of making irregular decorative spots on the faces of welds. The purpose of these spots, made with a pulsed laser, was to mask a characteristic arrangement of crystallisation isotherms (Fig. 17).

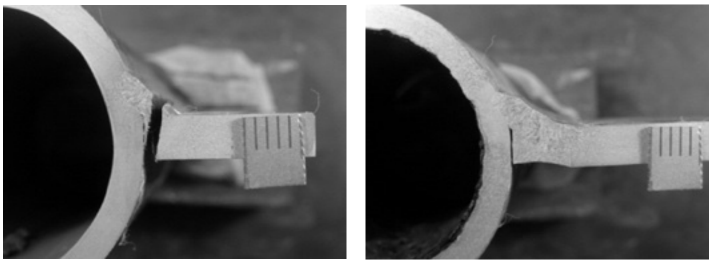


a) b)

Fig. 17. Joint of pipes (a) and laser-made decorative spots on the face of weld (b)

Tests of model joints of partly torn letters

The welding test also involved carrying out model repair welding of letters partly and entirely torn off the pipe. At the first stage it was necessary to produce T-shaped joints with fillet welds, joining the letters made of 4 mm -thick steel plate with the pipe (□33.9x3.2 mm). Afterwards, a passage groove in the fillet weld was made (to model the crack in the lower and upper part of the weld). The cuts were welded with a plasma arc. The technological conditions of plasma welding were as follows: weld groove I, distance 1.0 mm ÷ 1.5 mm, welding position PA, tungsten electrode WTh 20 □ 1.6 mm, plasma gas Ar, shielding gas Ar+2%H2, filler material – rod CastoTIG 45255W 2.0 mm in diameter, welding current 22 A÷26 A, plasma gas flow rate 0.3 l/min ÷ 0.4 l/min, shielding gas flow rate 6 l/min. A sectional view of a model crack before and after welding is presented in Figure 18.



a) b)

Fig. 18. Cut in fillet weld, modelling crack along the contact line between letter and pipe (a) and macrostructure of plasma-welded cut (b)

The welding tests and examinations demonstrated that the cracks in the joints between the letters and the pipe could be repaired by means of plasma arc welding and TIG welding. The application of these methods ensured proper fusion and filling of the weld groove formed through the crack.

Technological supervision

After the Conservation Section of the Museum had selected a company to perform repair welding i.e. company FormSerwis Sp. z o.o. (Ltd.) from Bydgoszcz, Instytut Spawalnictwa carried out the following technological supervisory works:

- verification of welding procedure specifications developed by the repair welding contractor. The technology developed for the welding of butt joints assumed that the root layer would be TIG welded, whereas the face layer would be laser welded. Afterwards, the face of the weld would be pulsed laser treated to obtain decorative spots,
- verification of qualification certificates of personnel performing the repair welding and assessment of test joints produced within the procedure of admission of TIG welder and laser welding operator to repair welding works,
- pre-welding inspection as to the completeness and serviceability of welding equipment.
- supervision over the production of the joints of the sign pipes,
- post-weld visual inspection of the welded joints of the sign.

Welding station

The welding station in a room of the locksmith’s shop of the Conservation Section of the Museum was equipped by company FormSerwis Sp. z o.o. with the following welding equipment:

- device Inverter-TIG-Power 1965 DC-HF -Puls, manufactured by Italian company CEBORA S.p.A., used for TIG welding,
- device ALM 200 manufactured by company ALPHA LASER, Germany, used for laser welding and surfacing by welding with a moving head (Fig. 20), provided with a welding

Fig. 19. Assembly table with fixed sign

wire feeder. The device is equipped with a pulsed laser Nd:YAG (wavelength: 1064 nm, average power 200 W, pulse energy 90 J). The device is mobile (1400x730x1505 mm, weight 345 kg), enabling welding in various places, often difficult to access. The movements of the arm with a turn-and-tiltable laser head are controlled by an operator with a joystick. Limitations are similar to those experienced while working with a TIG welding torch.

The welding station was also equipped with an assembly table provided by the Museum Preservation Department (Fig. 19). The table was used to fix and position the sign while welding so that a joint to be made was in PA position or a position close to PA (Fig. 21).

Summary

On the basis of the visual inspection of the damaged sign from the main gate to the former German Nazi concentration and extermination camp Auschwitz I, after its straightening and sand-blast cleaning, welding tests, examination of model joints and technological supervision over repair welding, it was possible to formulate the following conclusions:

Fig. 20. Mobile laser welding machine ALM 200

Fig. 21. ALM 200 laser welding of sign fixed on assembly table

1. Repair welding included the production of butt joints of the upper and lower pipes of the sign, welding of the sign-fixing elements as well as welding of cracks and torn elements according to a detailed list prepared on the basis of the visual inspection of the sign, following its straightening and sand-blast cleaning [6].

2. Repair welding was carried out by company FormSerwis Sp. z o.o., following the requirements specified by the Conservation Section of the Auschwitz-Birkenau State Museum [1, 2] and Instytut Spawalnictwa.

3. Visual inspection of the repair welded joints of the historic sign did not reveal any surface welding imperfections and thus confirmed the fulfilment of the acceptance criteria. During the repair welding the sign did not suffer from any deformities which would require straightening. The quality of the welded joints of the sign met the requirements of the Conservation Section of the Auschwitz-Birkenau State Museum as to the shape, dimensions and surface appearance.

The conservation, straightening and integration of the damaged sign were financed by the Auschwitz-Birkenau State Museum in Oświęcim. All the work conducted by Instytut Spawalnictwa related to material testing, technology applied for welding of the sign elements, determination of the scope of repair welding works after straightening of the sign, and technological supervision over the welding of the sign [5, 6] were free of charge (as was provided in the contract concluded with the Museum).

Prior to its exposition at a new main exhibition of the Museum, the re-integrated sign (Fig. 22) was subjected to further conservation.

Fig. 22. Sign after welding, removed from assembly table

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