

Explosion Cladding of Lead on Steel

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Abstract

This work deals with explosion cladding of lead on steel. The welded materials and the Semtex S type explosive are characterised. The preparation of the welded materials and the proposed welding assembly are described. The welding parameters, the welding conditions and the fabrication of the weld overlays are discussed. The quality of the fabricated bimetal was studied by optical and electron microscopy and by mechanical tests.

Keywords: lead, structural carbon steel, explosion cladding.

1 Introduction

As it is well known, fusion welding, soldering and thermal cutting of lead, including metals combined with lead, is at present prohibited in technical practice. In some cases, however, the use of lead is possible and/or unavoidable. Obvious examples are in the military and chemical industries. Bimetals of lead and other structural materials are interesting for the chemical industry. Bimetals such as Pb — structural carbon steel are attractive mainly owing to the high corrosion resistance of lead and the sufficient strength of steel. These bimetal are used for fabricating vessels for storing dangerous materials, e.g. H₂SO₄ 90 %, H₂SO₄ 60 %, PSCl₃ 95 %, PCl₃, NaNO₃. For storing aggressive media a lead layer on steel 3–5 mm in thickness is used depending on the corrosive medium. Until recently the interior of the chemical vessels was first tinned, and then a Pb layer was deposited on it. This procedure posed a great health risk for the persons performing the operations

even resulting in occupational diseases. To avoid this kind of risk solid state surfacing, namely by explosion cladding, has been selected as a more suitable technology.

2 Experimental

The materials selected for our experiments were as follows: 99.95% lead by STN 42 3701, and the steel type 11 373 by STN 42 5340, S235JRG1 by EN 10025A1. Owing to its low melting point, lead is used with working temperatures only from 150 to 170 °C. Only technically pure lead is used in the chemical industry as pure lead has the highest resistance against corrosion. The chemical resistance of lead in some environments may be increased by the addition of a small amount of H₂SO₄ to provide a protective layer on the material surface. So-called “hard lead” is not suitable for welding, since it causes embrittlement of welded joints. The chemical composition of the welded materials is shown in Tables 1 and 2.

Table 1: Chemical composition of Pb 99.95

Pb 99.95 by STN 42 3701 [wt.%]								
Pb	Ag	Bi	Cu	Sb	As	Fe	Zn	Sn
min.	max.	max.	max.	max.	max.	max.	max.	max.
99.95	0.0015	0.030	0.0015	0.005	0.002	0.002	0.002	0.002

Table 2: Chemical composition of steel type 11 373

Steel type 11 373 by STN 42 5340 [wt.%]				
C	N	P	S	–
max. 0.170	max. 0.007	max. 0.045	max. 0.045	–

Table 3: Physical properties of lead

Physical properties of Pb 99.95	
Density ρ [$\text{kg} \cdot \text{m}^{-3}$]	11 341
Elasticity modulus in tension E [MPa]	$(14.71 \text{ to } 17.65) \cdot 10^{-3}$
Elasticity modulus in shear G [MPa]	$6.865 \cdot 10^{-3}$
Sound propagation velocity v [$\text{m} \cdot \text{s}^{-1}$]	1 200

Table 4: Mechanical properties of steel type 11 373

Selected mechanical properties of steel type 11 373	
Yield point $R_{p0.2}$ [MPa]	225
Ultimate tensile strength R_m [MPa]	363 to 441
Minimum ductility A_5 [%]	25

Table 5: Cladding parameters (charge thickness H , explosive density ρ , detonation velocity v_d , distance spacing h , setting angle of accelerated metal $[\circ]$, deviation angle of accelerated metal $[\circ]$, collision velocity v_k , final velocity v_0)

No.	H [mm]	P [$\text{g} \cdot \text{cm}^{-3}$]	v_d [$\text{m} \cdot \text{s}^{-1}$]	h [mm]	α [\circ]	ϑd [\circ]	v_k [$\text{m} \cdot \text{s}^{-1}$]	V_0 [$\text{m} \cdot \text{s}^{-1}$]	Expl. type
1	31.6	0.980	1 336	5.1–9.8	2.23	8.6–8.9	1 060–1 070	207	SP-14
2	31.5	0.984	1 340	7.5	0	8.8	1 340	208	SP-14
3	50.8	1.090	1 454	7.2	0	12.6	1 454	343	SP-14
4	50.7	1.110	1 474	7.0–13.1	2.80	12.7–13.5	1 210–1 230	351	SP-14
5	51.7	1.030	1 390	8.0–17.5	4.35	12.5–13.1	1 040–1 050	320	SP-14
6	51.5	1.260	1 250	8.0–17.5	4.35	–	–	–	SN-12
7	51.8	1.250	1 250	8.8–18.0	4.26	–	–	–	SN-12
8	21.6	1.156	1 990	4.9–22.7	8.10	9.1–9.6	1 070–1 080	332	S-25

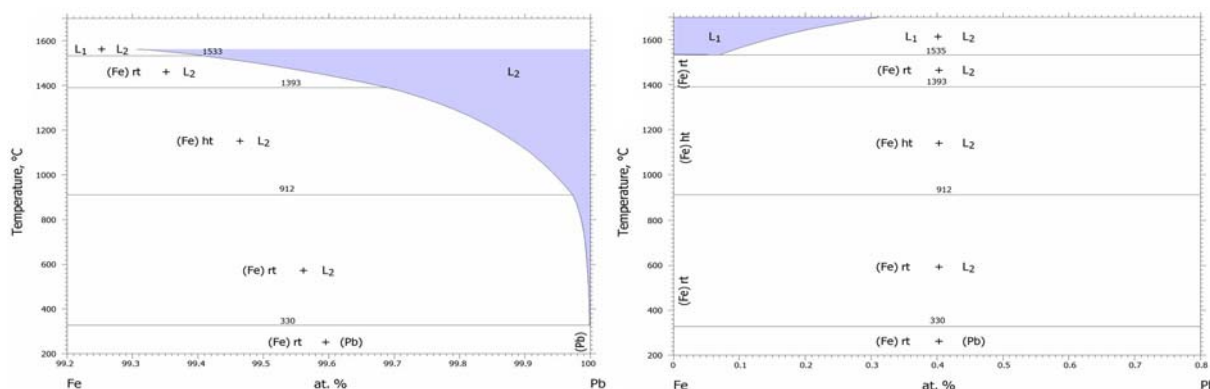


Figure 1: Parts of the Fe–Pb binary diagram

The physical and mechanical properties of Pb and steel needed for the welding process are presented in Tables 3 and 4.

The parameters of the cladding process are given in Table 5.

Prior to welding, it was necessary to make a detailed study of the Pb — steel binary diagram, and to

ascertain the possibility that undesired phases might be formed (Figure 1).

All materials to be explosion welded must be free from impurities and organic deposits, irrespective of the cleaning effect of cleaning agents. The weld surfaces on steel were machined by grinding to roughness $R_a = 3.2 \mu\text{m}$, and shortly before welding they

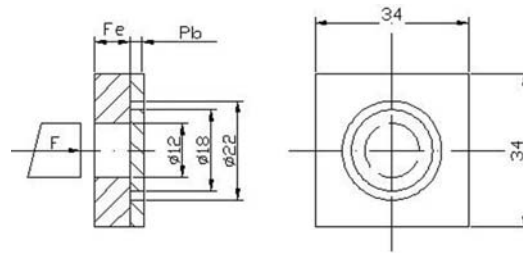


Figure 2: Scheme of the peel test

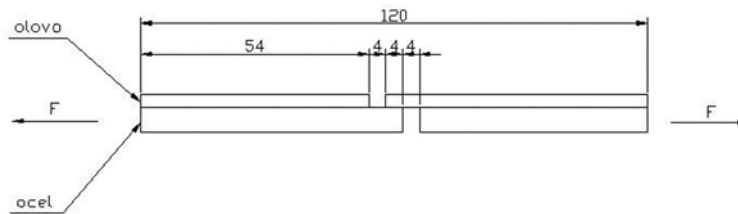


Figure 3: Shear test of the bimetal

were degreased with acetone. The lead was straightened prior to welding, cleaned with a steel brush and degreased with acetone.

The welding parameters are given in Table 5. The explosives for explosion welding do not form a unified group. They need to have specific properties for each technological process. To achieve good process reproducibility, the explosive that is used needs to have a stable detonation regime in non-sealed charges. Loose Semtex S type explosives were used for fabricating Pb — steel bimetal. These explosives were manufactured at RIICH Synthesia, Pardubice. After welding, the bimetal was cleaned from detonation products with a brush under running water and was then prepared for further study.

The following assessment methods were applied for our study of the quality of the fabricated bimetal joints: ultrasonic defectoscopy, mechanical tests, corrosion resistance tests and metallographic investigation.

2.1 Ultrasonic defectoscopy

The inspection was performed from the lead side. Probe coupling was ensured by the use of oil. The tests were performed using the USIP 11 equipment with a MSEB 6H probe with 6 MHz frequency. No defects were found in the joint boundary zone. The initial 3.2 mm thickness of the lead plate was reduced to 2.8 to 3.0 mm owing to the high detonation velocity and compression.

2.2 Mechanical tests

The quality of the fabricated joints was assessed by the following mechanical tests: a peel test, a shear strength test, and a bend test.

Peel test: an ordinary shop hydraulic press was used for this test. It must be stated that this test

is not standardised and therefore it serves only to provide information on the boundary quality. The scheme of the test specimens is shown in Figure 2. The test showed that the boundary remained undamaged and the punch penetrated through the lead.

Shear strength test: three specimens with dimensions as shown in Figure 3 were cut from the bimetal in the direction of detonation wave propagation. Failure of the specimens occurred on the lead side. This suggests that the lead — steel boundary is of higher strength than the pure lead, thus proving sufficient joint strength. The tensile strength of the initial lead used for cladding was determined to be 12.8 MPa.

The bend test is presented in Figure 4. Similar specimens to those used for the tensile test were machined from the fabricated bimetal. The specimen was firmly clamped in a vice and its free end was bent by 180° around a mandrel of $\varnothing 14$ mm in diameter. The specimen was placed in such a manner that the notch face included a 30° angle with the normal plane. The boundary was so strong that no damage occurred even when the mandrel diameter was reduced to $\varnothing 8$ mm.

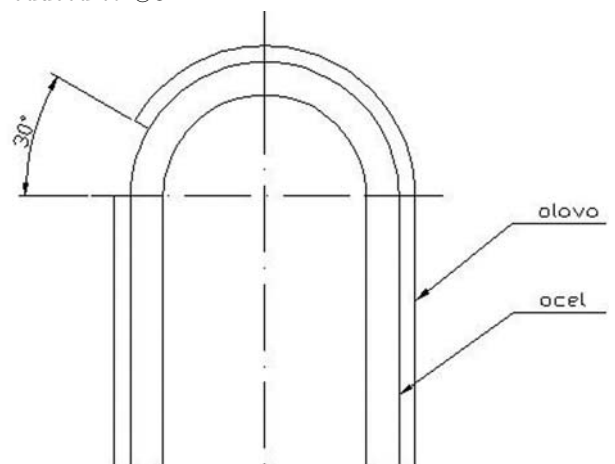


Figure 4: Scheme of the bend test of the bimetal

2.3 Metallographic assessment of the welded joints

Observation by optical microscopy showed that the basic structure of the steel was polyhedral, locally deformed on the boundary. The thickness of the deformed layer was around 0.5 mm. The measured wave amplitude was 0.08 to 0.1 mm, and the waving period was 0.48 to 0.53 mm. The weld boundary is shown in Figures 5 to 8.

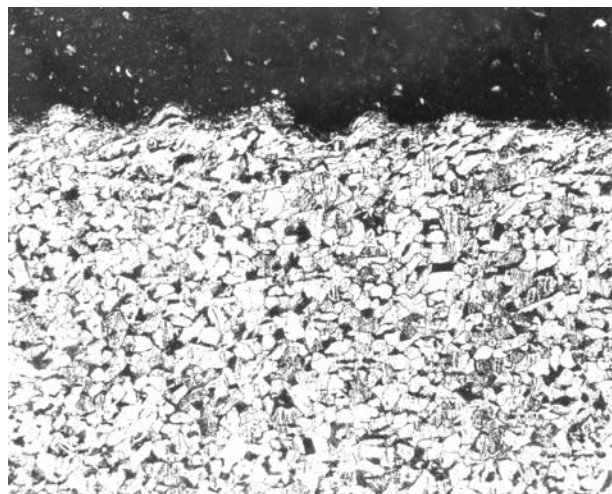


Figure 5: Weld boundary of the lead — steel bimetal 110×

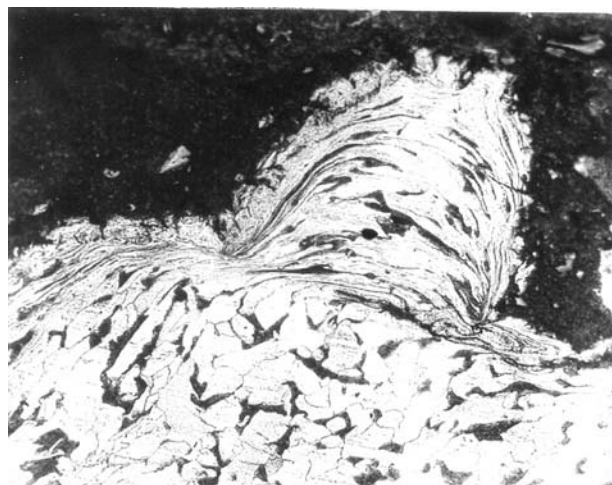


Figure 6: Weld boundary of the lead — steel bimetal 600×

A more detailed assessment of the character of the fractured surfaces of a Pb — steel welded joint was performed by scanning electron microscope (SEM). The specimens from which the lead was torn off in the peel test were observed. It was observed that failure occurred after preliminary plastic strain, mostly by ductile fracture. Figures 7 and 8 show the ductile

fractures in the lead which progressed to the darker zones where insufficient bonding of materials was observed. The bonding of Pb to the parent steel material was around 55 %.

Figures 7 and 8 show the fractures after fusing down of Pb from the steel surface in a vacuum.

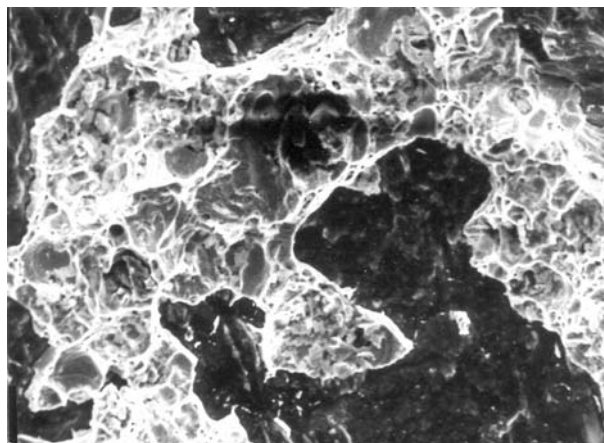


Figure 7: Ductile fracture in the lead (REM) 500×

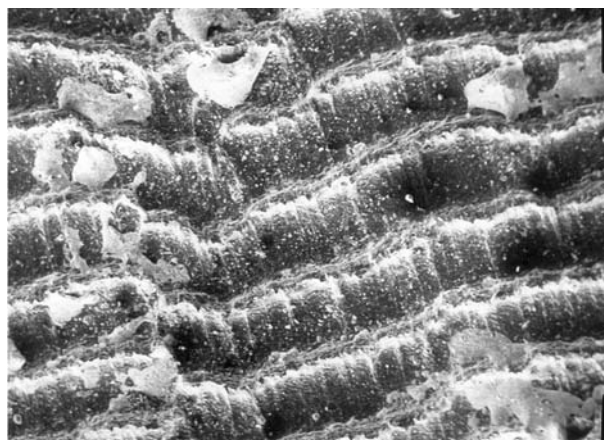


Figure 8: The lead fused from the steel surface 500×

3 Conclusions

The aim of our study was to develop and test a special technology for lead cladding on a steel plate made of structural carbon steel. A total of 8 bimetallic welded joint swith dimensions of 120 × 120 × 14 mm were fabricated. On the basis of our results it can be stated:

Sound welded joints were fabricated by explosion cladding with optimum parameters. A new explosive was tested and it was found to be suitable for cladding the lead. Mechanical testing (a peel test, a shear test, and a bend test) of the bimetals proved their high quality. The failure of the specimens occurred on the lead side during the shear test. The boundary was so strong that no damage occurred

even when the mandrel diameter was reduced to $\varnothing 8$ mm in the bend test. The peel test showed that the boundary remained undamaged and the punch penetrated through the lead.

On the basis of our experience and results it may be stated that this technology is promising one for fabricating bimetals. It is important to emphasize that the technology we have developed possesses no health hazards unlike the risky process of lead surfacing by flame.

Acknowledgement

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