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Influence of Diffusion Welding Time on Homogenous Steel Joints

Ladislav Kolařík[a]*, Jiří Janovec[b], Marie Kolaříková[a], Pavel Nachtnebl[a]

[a]*CTU in Prague, Faculty Of Mechanical Engineering, Department of Manufacturing Technology, Prague 6, 16607, The Czech Republic*
[b]*CTU in Prague, Faculty Of Mechanical Engineering, Department of Material Engineering, Prague2, 12135, The Czech Republic*

Abstract

The paper deals with assessment of influence of welding time on welding joint creation. Diffusion welding method in inert gas (Ar 4.8) at low pressure was used. Homogenous welding joints were created from steel E296 (according to EN ISO 10025-2). Homogeneous welds were done for easy assessment of influence of diffusion welding time and temperature on resulting welding interface, which was closely observed. Due to diffusion of carbon and manganese, on the joint interface were created complex iron and manganese carbides $(FeMn)_3C$. It was found that the amount of created carbides depended on temperature and time. At temperature 1000 °C the biggest quantities of carbides were created, already at time 900 s the continuous carbidic strip was created with thickness 1-2 µm. This strip is very brittle and is detrimental to joint properties.

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Keywords: Diffusion Welding; Homogenous Steel Joins; Metallography; Electron microanalysis

1. Introduction

Diffusion welding is a process, when the welded parts are in close contact under controlled pressure heated to defined temperature and for specific time. Necessary conditions are local plastic deformation and maximal surface approximation, which allow atomic diffusion between two welded parts and creation of high strength joint [1, 2].

From a historical point of view the diffusion welding is newer technology, which has applications in many industries, such as electronics, automotive, aerospace and space industries.

Diffusion welding is mainly used for joining of difficult to weld materials [3, 4] or when standard fusion welding

* Corresponding author. Tel.: +420-224-352-619; fax: +420-224-310-292.
E-mail address: ladislav.kolarik@fs.cvut.cz

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methods can´t be use, e.g. high strength steels, high alloy steels, refractory metals, super-hard, materials with high affinity to oxygen and so on. This method is also used for welding of heterogeneous joints [5, 6, 7], similarly as laser welding [8, 9], electron beam welding [10] and explosion welding [11].

In the future it is expect that the diffusion welding will expand especially for saving deficit metals and for heterogeneous joints, advanced construction materials. The research of new materials with special mechanical and physical properties, contribute to further development of this method.

At Department of manufacturing technology, Faculty of mechanical engineering, CTU in Prague in present time starts research of this welding process (which is also included in this paper).

2. Experimental

In literature the influence of temperature is evaluated as the most important parameter for diffusion welding. In this paper the influence of second basic parameter, i.e. welding time is researched. For research of influence of welding time on joint quality was chosen for simplicity the steel E295 (according EN ISO 10 025-2). There were produced homogenous diffusion joints at various welding times. Diffusion welding is usually used for materials which are difficulty welded. However, steel E295 was chosen on purpose, to observe easily formation of phases at the joint boundary. For alloyed steels more complex phases would be created rendering the research relatively complicated. E295 was chosen because it provides greater assurance of achieving quality joint – these is no presumption of creating complicated diffusion processes and strips as in case of heterogeneous joints or homogeneous joints from difficulty welded materials (creation of intermetallic phases etc.).

2.1. Base material

The base material, steel E295, (according to EN ISO 10025-2; 1.0050 according to EN ISO 10025-1) is unalloyed structural steel of common quality. The steel has worse chemical purity, which is prescribed “only” by definition of impurities content - P and S, and by basic mechanical and technological properties (see tab. 1 and tab. 2). Fusion weldability of this steel is similar as for [12].

Table 1. The standard chemical composition of steel E 295 in % of weight.

The element	Wt. %
P	Max 0.045
S	Max 0.045
N	Max 0.009

Table 2. The basic mechanical properties of steel E 295 according inspection certificate.

Mechanical property	[MPa]
Tensile strength $\mathbf{R_m}$	470-610
Yield strength $\mathbf{R_e}$	245-295
Fatigue strength in bending $\boldsymbol{\sigma_{oc}}$	175-215
Fatigue strength in torsion $\boldsymbol{\tau_c}$	125-155
Ductility A_5[%]	16-20

The spectral analysis was performed by equipment Q4 Tasman to verify real chemical composition (tab. 3), which is desktop spark optical emission spectrometer from German producer Bruker-Elemental. The microstructure of base material is shown at Fig 1.

Table 3. Comparison of measured chemical composition and standardized values [wt. %].

C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Al
0.325	0.244	0.682	0.012	0.015	0.052	0.010	0.015	0.022	0.013
-	-	-	max. 0.045	max. 0.045	-	-	-	-	-
As	**B**	**Co**	**N**	**Nb**	**Sn**	**Ti**	**V**	**W**	**Fe**
0.003	0	0.001	0.003	0.002	0.002	0.001	0.002	< 0.005	98.541
-	-	-	max. 0.009	-	-	-	-	-	-

[1st] row – measured values, 2[nd] row –standard, prescribed composition

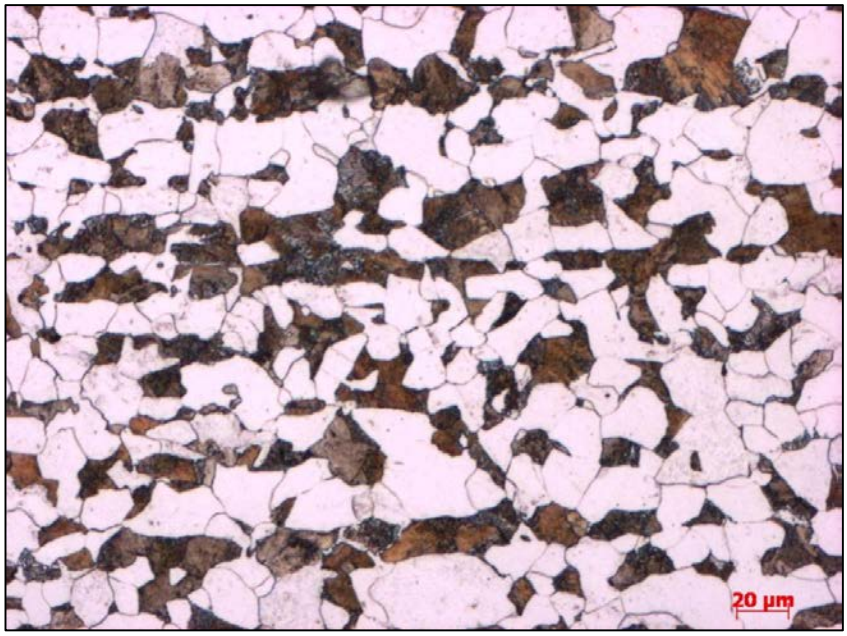

Fig. 1. Microstructure of base metal - steel E295.

2.2. Used equipment and welding parameters

The equipment SU450 (Indutherm company) was used [13]. Main welding parameters are temperature, time and contact pressure. During all experiments was pressure set to maximal value 0.25 MPa, yet for steel it is quite low and should be higher for steel material.

Welding temperature was chosen according to [1, 3, 4] in range from 0.6 to 0.7 of melting point of base material. Various additives contained in the molten steel reduce the liquidus temperature and usually also solidus temperature. Formula 1 shows the calculation method of liquidus temperature of the steel with consideration of influence of the content of various elements to reduce t_L according to T. Myslivec [14]. Formula is based on melting point of pure iron 1 536°C.

$$T_L = T_{Tk} - \left(\%a \cdot \Delta T_L^a + \%b \cdot \Delta T_L^b + ... + \%n \cdot \Delta T_L^n\right) \quad (1)$$

$$= 1536 - (0.325 \cdot 73 + 0.244 \cdot 12 + 0.682 \cdot 3 + 0.012 \cdot 28 + 0.015 \cdot 30 + 0.052 \cdot 1 + 0.015 \cdot 3.5) = 1506\ °C$$

The temperature was set to 1 000°C, which approximately corresponds to 65% of melting point of base material. Welding times were set to be 300, 600 and 900 seconds, for sample 1, 2, 3 respectively.

During process of diffusion welding, samples inside the working chamber were protected by inert atmosphere – Argon 4.8. Before the beginning each diffusion process, the triple backwash of vacuum pump was made which suctioned all gas atmosphere of the working chamber and fills it with inert gas.

2.3. Sample size

As samples, cylinders of diameter 30 mm and thickness 5 mm were prepared and welded together by above stated parameters. The samples were evaluated by optical microscopy and then by electron microanalysis.

3. Results

3.1. Optical microscopy

The interface of welded parts is always in the middle of shown figures (fig. 2 to 4 have 1000x magnification).

As we can see at Fig 2 (sample 1), at the interface there are visible continuous ferritic grains boundaries from one welded part to second (marked with red lines). Pearlitic grains are marked with circles. There are many dark particles both at interface and in its neighborhood, some are marked with arrows. These particles were identified as complex carbide of iron and manganese in following experiment.

With longer welding time $\mathbf{t_s}$ (dwell on temperature 1 000°C), the ferritic grains near interface grow in size. Also we can notice growth of carbidic particles in size and number, i.e. density. On Fig 4 (sample 3), these particles create compact and continuous layer (carbidic strip) along original interface of welded parts.

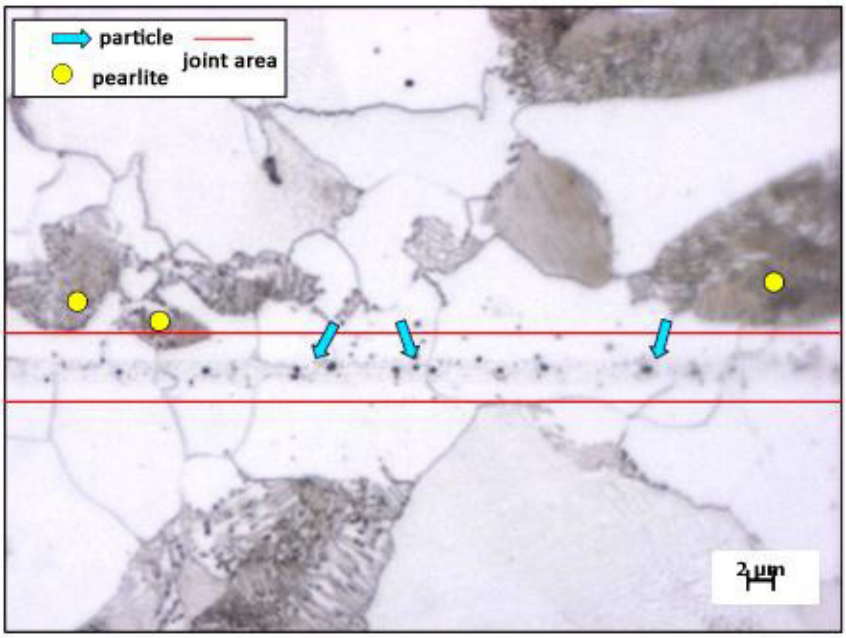

Fig. 2. Microstructure of sample 1: T = 1 000°C; t_s = 300 s.

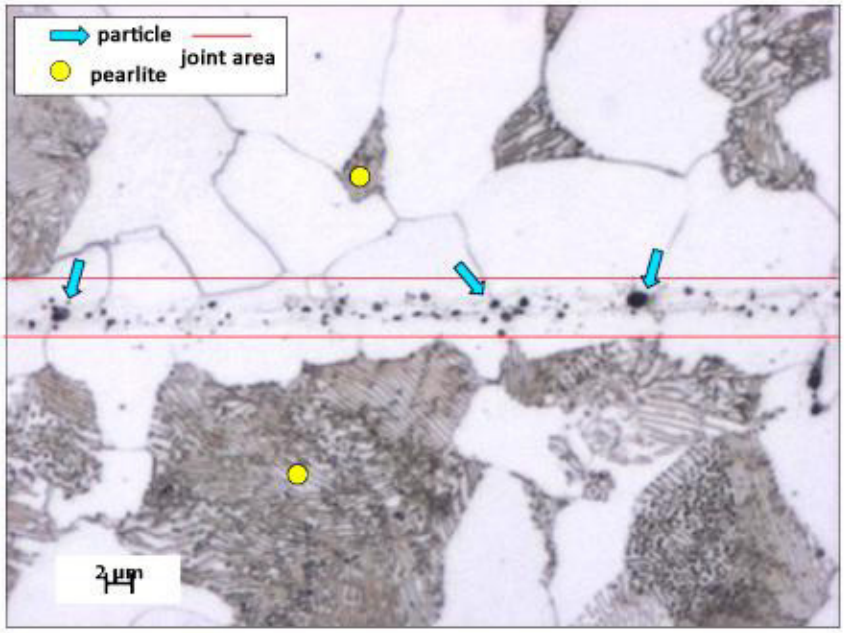

Fig. 3. Microstructure of sample 2: T = 1 000°C; t_s = 600 s.

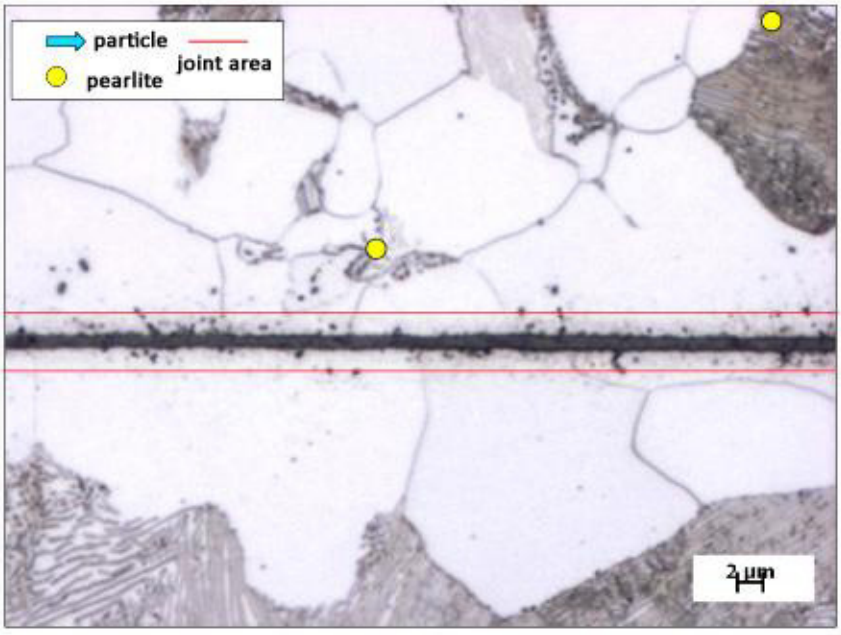

Fig. 4. Microstructure of sample 3: T = 1 000°C; t_s = 900 s.

Electron microanalysis

The chemical composition of the dark particles at the joint interface was analyzed by electron microanalyzer Camebax MICRO (from French company CAMECA) and by energy dispersive analyzer from company KAVEX. Control microprocessor PDP 11/23 was used (company DEC) [15].

3.2. Qualitative spectral analysis

For analysis, crystals LiF, ODPb, TAP and PET were used. On the base of spectrogram, as e.g. on Fig 5 we identified present elements, results shown at table 4.

By analysis ferritic and pearlitic grains were identified. Two dark particles were analyzed, the identical elements were found for both particles.

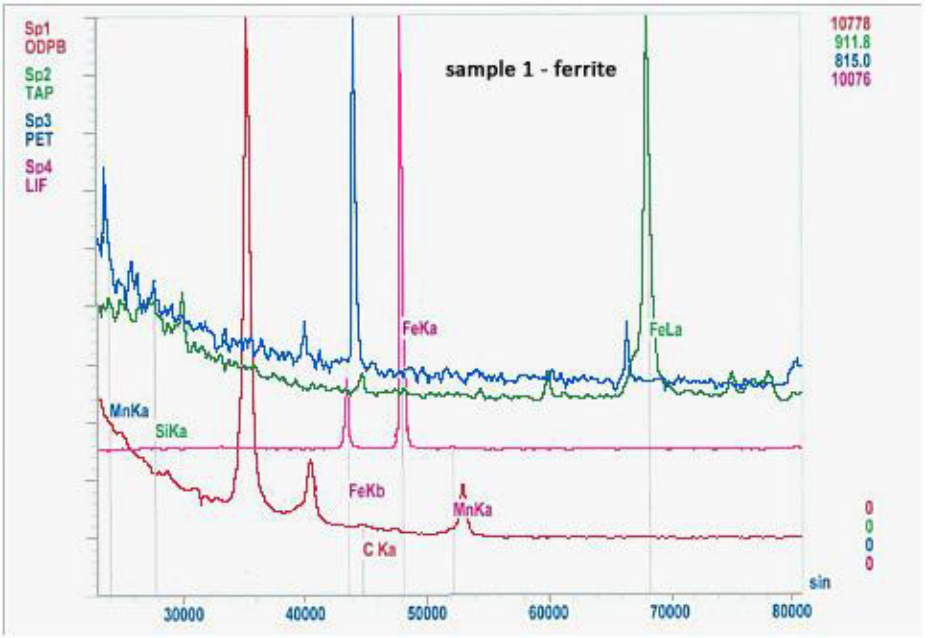

Fig. 5. Example of qualitative spectral analysis on Sample 1.

Table 4. Identified elements on sample 1 (Ts = 1 000°C; t_s = 300 s).

area	Identified elements
ferrite	Fe, Mn, Si, C
pearlite	Fe, C, Mn, Cr, Si
particle 1	Fe, C, Mn, Si, Cr

3.3. Spot quantitative analysis

The results of quantitative analysis are in table 5. Every value is made as average from five measurings.

Contents of elements (detected by quantitative spectral analysis) were measured - C, Mn, Cr, Si (Fe was calculated as balance). On sample 1 the measurement was made in 4 areas: supposed ferritic grain, supposed pearlitic grain, unknown dark particle on interface of joint and area between ferritic grains.

The ferritic grain was analyzed about 100 μm from joint interface (in table is marked as: ferrite-100μm). For comparison the ferritic grain was measured in close proximity to joint interface (marked: ferrite – joint), it was maximally 5 μm from joint interface.

It was derived from these results that dark particles are complex carbides of iron and manganese type $(FeMn)_3C$. According to our hypothesis, these carbides are formed by diffusion of carbon and manganese from pearlitic and ferritic grains. We can infer this also from comparison of chemical composition of ferritic grains (grain close to joint and 100 μm far). The farther ferritic grains have manganese content 0.97 % of weight. Grains close to joint have much lower manganese content - 0.21% of weight.

Table 5. Identified elements for sample 1 (Ts = 1 000°C; t_s = 300 s) [wt. %].

elements	**ferrite-100 µm**	**pearlite**	**ferrite - joint**	**dark particles**
C	0.02 ± 0.01	2.43 ± 0.20	0.01 ± 0.01	3.66 ± 0.19
Si	0.22 ± 0.02	0.34 ± 0.05	0.21 ± 0.02	0.40 ± 0.02
Cr	0.17 ± 0.02	0.07 ± 0.03	0.13 ± 0.01	0.05 ± 0.02
Mn	0.97 ± 0.06	1.32 ± 0.18	0.21 ± 0.02	11.59 ± 0.86
Fe	98.62 ± 0.08	95.84 ± 0.33	99.43 ± 0.04	84.31 ± 0.73

4. Discussion

Theoretically for homogeneous joints the interface between welded parts should completely disappear. [3, 4] – see fig 6.

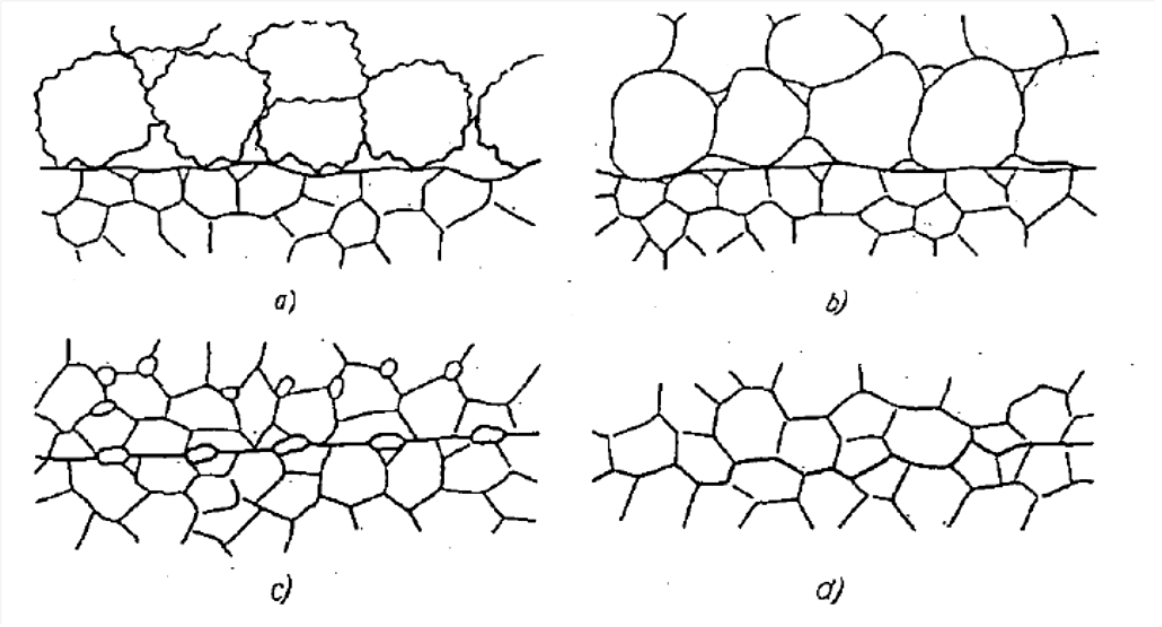

Fig. 6. Stages of creating diffusion joint [3], (a) The first contact, migration of atoms and bridges creation, (b) The plastic alignment of micro-roughness, (c) The intensive diffusion and micro-deformation, (d) The ideal diffusion joint.

But in our research, the interface is very well visible; see photos above (fig 2 - 4). New crystalline grains were formed only at certain places, but according to recrystallization hypothesis, these new grains should belong to both welded parts [1, 3, 4]. This process is time restricted dependent.

Based on the above findings, it can be said that longer welding time $\mathbf{t_s}$ creates diffusion of C and Mn, i.e. depletion of C from pearlitic phase and depletion of Mn from ferritic phase to form particles of carbide $(FeMn)_3C$. These carbides create clusters together in area of joint interface. With higher welding temperature, this diffusion process is more intensive and much more carbidic particles are formed.

Conclusion

During the experiment it was proved that beside temperature of welding process, the welding time also has big influence on results. Carbidic particles were formed on interface of joint during welding process. Amount of carbidic particles increased with temperature and time. Carbides formed continuous layer (carbidic strip) with thickness 1 to 2 μm on joint interface at maximal values of parameters used for experiment. This layer is very brittle and worsens mechanical properties of the joint. Next disadvantage of long-time high-temperature load of sample is significant influence of microstructure of base material. There is assumption that some limited amount of created carbides will be increasing the joint strengths, yet too high value is causing joint brittleness. Confirmation of this hypothesis will be the subject of further research.

Acknowledgements

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