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# The Chemical Composition of the Weld Deposit in Metallic Products Made Using Wire Arc Additive Manufacturing Methods

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**Abstract:** The article presents an analysis concerning the obtainment of weld deposit properties (declared by the manufacturer of the filler metal) in the finished products made using additive manufacturing processes involving the application of arc welding methods. The use of an incompatible base material during the initial stage of the additive manufacturing process led to significant changes in the chemical composition of the obtained layer (when compared with the chemical composition of the weld deposit declared by the producer of the filler metal). The dilution of the partly melted incompatible base material with the weld deposit resulted in the obtainment of a layer characterised by different properties (i.e. microstructure, hardness, corrosion resistance) than those declared by the manufacturer of the filler metal. The results obtained in the tests described in the article were compared with the requirements related to the making of the weld deposit subsequently subjected to the analysis of chemical composition (in accordance with the PN-EN ISO 6847 standard). The requirements specified in the aforesaid standard are used during tests related to, among other things, the conformity assessment procedure applied when qualifying filler metals.

**Keywords:** WAAM, wire arc additive manufacturing, filler metal, weld metal, 3D printing

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## Introduction

Wire Arc Additive Manufacturing (WAAM) enjoys growing popularity with researchers and becomes increasingly often applied among other additive manufacturing methods. According to the Scopus database, there are increasingly many scientific publications containing the key acronym of WAAM (*Wire Arc Additive Manufacturing*). The use of conventional welding methods enables the making of three-layered elements, on a layer-by-layer basis. Similar to welding processes, it is important to properly adjust filler metals to base materials. In terms of additive manufacturing it is important to properly adjust base materials to filler metals used in the process. Obviously, the most favourable solution should involve the use of adjusted materials having the same chemical composition, yet it is not always possible [1-5]. The article presents the obtainment of chemical weld deposit

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in the first layers of metallic materials using wire arc additive manufacturing methods. The analysis involved simple products made using an additive manufacturing process based on the gas-shielded metal arc welding technique and was confronted with requirements concerning the performance of the analysis of the chemical composition of weld deposit in accordance with the ISO 6847 standard.

## Weld deposit and the analysis of its chemical composition in accordance with ISO 6847

The analysis concerning the chemical composition of weld deposit related to the assessment of compatibility when qualifying filler metal types or testing batches of filler metals should be performed in accordance with recommendations contained in the ISO 6847 standard [6]. Table 1 presents filler metals and corresponding welding processes, to which the current standard applies.

Table 1. Filler metals and corresponding welding processes applied in the chemical composition analysis in accordance with ISO 6847

| Filler metal | Welding process |
|---|---|
| Covered electrode | 111 |
| Solid wire | 141, 145 |
| Flux-cored wire | 143, 146 |
| Solid electrode wire | 131, 135 |
| Flux-cored electrode wire | 114, 132, 133, 136, 138 |
| Wire-flux combinations | 121, 722 |
| Strip-flux combinations | 122, 721 |

The test aimed to identify the chemical composition of the base material should be performed using a 15 mm thick plate (in relation to submerged arc welding processes) or a 10 mm thick plate (in relation to other processes) having a chemical composition similar to the weld deposit or made of structural steel (C-Mn) having a carbon content ≤ 0.2%. Materials subjected to cladding are made of structural steel (C-Mn) having a thickness of 25 mm as well as a carbon content of ≤ 0.15% and a content of Cr, Mo, Nb and Ni ≤ 0.10%. Before the test, the surface should be cleaned by removing rust, cinder, grease or paint (e.g. by sanding/grinding). Pre-test preparations should also involve filler metals. The drying of filler metals (covered electrodes, fluxes used for submerged arc welding or electroslag welding) should be performed under conditions specified by the manufacturer. Flux-cored electrodes can be dried on supports following the producer's instructions. The process should be performed in the flat position (PA) (in accordance with ISO 6947), using the type of current and its polarity as specified by the producer. However, in cases where a given material is used for welding involving the application of both direct (DC) and alternating (AC) current, the test should be performed using alternating current (AC). The remaining current-voltage conditions (subject to recording during the test) should follow the requirements of a given standard concerning the classification of a filler metal (e.g. ISO 2560, ISO 14341, etc.). If the aforesaid conditions are not specified in a related standard, each layer should be welded using current restricted within the range of 70% to 90% of the maximum current value specified by the producer. The ISO 6847 standard provides for 8 methods related to the application of weld deposit in the analysis of chemical composition (see Fig. 1). Once a given layer has been made, the specimen should be cooled in water for 30 seconds and dried before the deposition of another layer; slag, if any, should be removed. During the deposition process, the direction of welding should be changed (for each subsequent layer).

Specimens for chemical analysis should be sampled from the fifth weld deposit layer or higher, from areas distant from the beginning of the layer and of the crater, after previously removing the oxide layer from the weld deposit surface (e.g. by means of grinding or machining, without the use of cooling liquid).

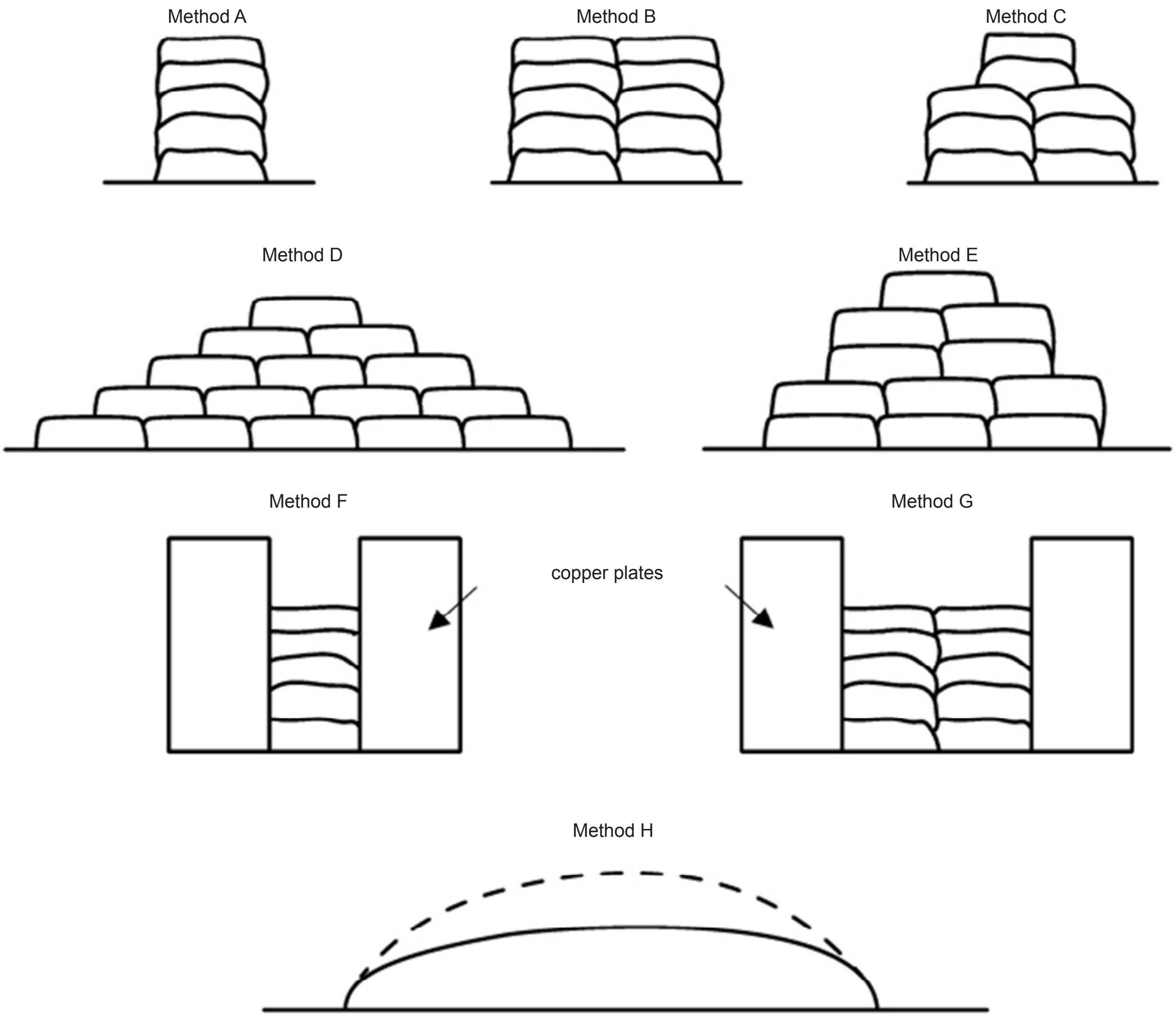

Fig. 1. Weld deposit application methods

## Additive manufacturing in the MIG welding process (131)

The additive manufacturing process involved the use of a MIG welding (131) station equipped with a ZASO Scorpio Micro welding tractor, a Kemppi FastMIG KMS 400 welding machine and a Kemppi MXF 65 filler metal wire feeder. The process was performed on a layer-by-layer basis, maintaining an inte rpass temperature of not more than 150°C. A heat input was identified using method A described in the ISO/TR 18491 standard (1).

$$Q = \eta \frac{I \cdot U}{v_{sp}}, \frac{kJ}{mm} \qquad (1),$$

where $Q$ – heat input, $I$ – current, $U$ – arc voltage, $v_{sp}$ – welding torch travel rate (welding rate) and $\eta$ – arc efficiency ($\eta = 0.8$ in accordance with EN 1011-1).

The base materials used in the process were 15 mm thick plates made of steel X6CrNi25-20 (AISI 310) and steel S235JR. The filler metal used in the process was a MIGWELD 307Si solid wire (EN ISO 14343-A: G 18 8 Mn) (METALWELD FIPROM POLSKA). The parameters used in the process are presented in Table 2. The weld pool was shielded by inert gas (argon).

The two test plates (80 mm in length and 25 mm in height) corresponded to weld deposit application method A in accordance with the ISO 6847 standard. The main view of the products after the performance of the additive manufacturing process is presented in Figure 2. The individual layers were deposited

Table 2. Parameters of the MIG method-based (131) additive manufacturing process

| Base material | Layer | Current $I$, A | Voltage $U$, V | Heat input $Q$, kJ/mm |
|---|---|---|---|---|
| X6CrNi25-20 | 1÷9 | 174.0±17.6 | 19.0±0.59 | 0.63±0.05 |
| S235JR | 1÷9 | 173.0±14.1 | 18.9±0.35 | 0.63±0.04 |
| Filler metal wire feed rate $v_{dr}$, m/min | | | | 5.6 |
| Welding torch travel rate $v_{sp}$, m/min | | | | 0.25 |
| Electron extension $l$, mm | | | | 5.5 |

interchangeably, where the deposition of a successive layer started at the end of the previous one. As a result, each successive layer was shorter than the previous one.

Fig. 2. Main view of the additive manufactured products: a) specimen 1 – base material X6CrNi25-20 and b) specimen 2 – base material S235JR

The analysis concerning the chemical composition of weld deposit involved macro and microscopic analysis as well as energy dispersive spectroscopy (EDS). The preparation of test specimens involved the obtainment of the cross-section of both specimens (using a water-cooled saw) followed by metallographic preparation, including sanding, mechanical polishing and electrolytic etching in a 10% chromic acid solution and a 20% sodium hydroxide solution.

The macro and microstructure analysis involved the cross-section of both specimens and was performed using a Stereozoom S9i light microscope and a Leica DM/LM light microscope. The chemical composition analysis was performed using an EDS detector installed on a PHENOM XL scanning electron microscope. The generation of X-radiation from an area of 0.37 mm$^2$ was obtained using an electron beam having an accelerating voltage of 20 kV and a current of 15 nA.

The macrostructure of the specimens is presented in Figure 3. In terms of specimen no. 2 (base material S235JR), the cross-section contained two gas pores (welding imperfection no. 2011 in accordance with ISO 2560-1) in the second and seventh layer respectively. No other welding imperfections were detected in the above-named layers. In addition, it was impossible to maintain axiality between individual layers, which could be ascribed to the free deposition of the filler metal leaving the welding torch and not subjected to straightening. However, the aforesaid situation (along with the above-named welding imperfections) did not affect the analysis results. The boundaries between the individual layers of the weld deposit were clearly visible. The first layer of both specimens was characterised by post-etching material discolouration

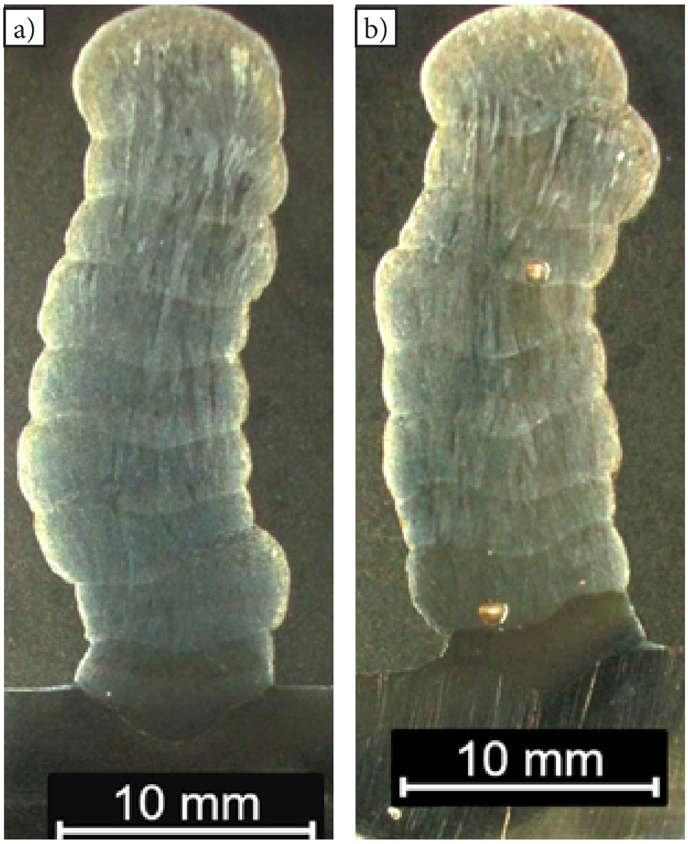

Fig. 3. Macrostructure of the specimens after additive manufacturing: a) specimen 1 – base material X6CrNi25-20 and b) specimen 2 – base material S235JR

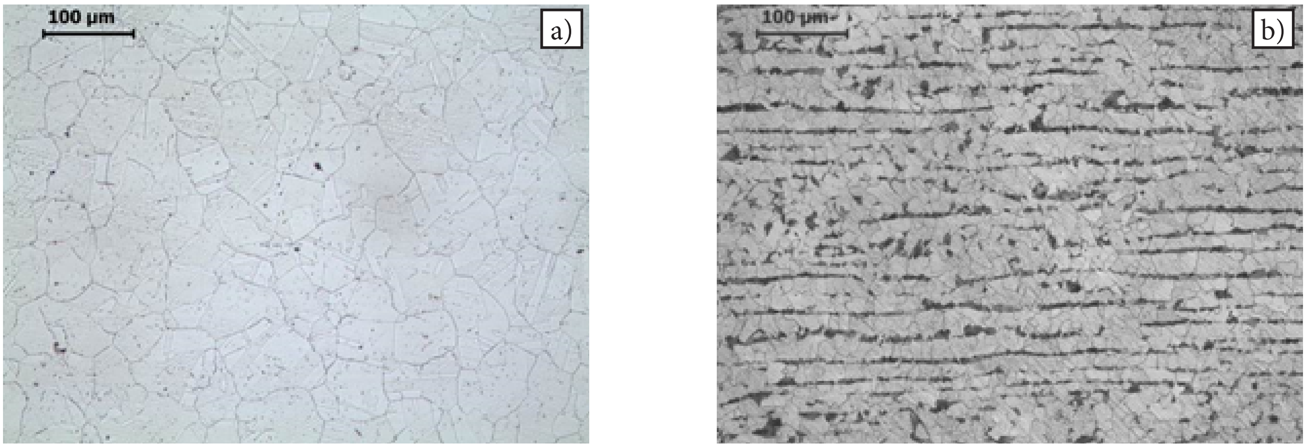

Fig. 4. Microstructure of the specimens after additive manufacturing: a) specimen 1 – base material X6CrNi25-20 and b) specimen 2 – base material S235JR

(in comparison with the other layers). In spite of the process direction changes following the making of each layer, it was also possible to notice the presence of the transcrystalline structure between the individual layers.

The microstructure of the base material in both specimens is presented in Figure 4. Steel X6CrNi25-20 (AISI 310) is characterised by the twinned austenitic microstructure (Fig. 4a), whereas steel S235JR is characterised by the banded ferritic-pearlitic structure (Fig. 4b).

The microstructure of the individual layers of both specimens is presented in Figures 5 and 6. All of the layers were subjected to analysis, yet only the microstructure of layers 1-4 is presented in the above-named Figures. Layers 5-9 were characterised by the microstructure, which did not differ significantly from that observed in layer 4. In specimen 1 (Fig. 5) and specimen 2 (Fig. 6) it was possible to observe the austenitic microstructure with intercellular ferrite-δ across the entire cross-section. As regards

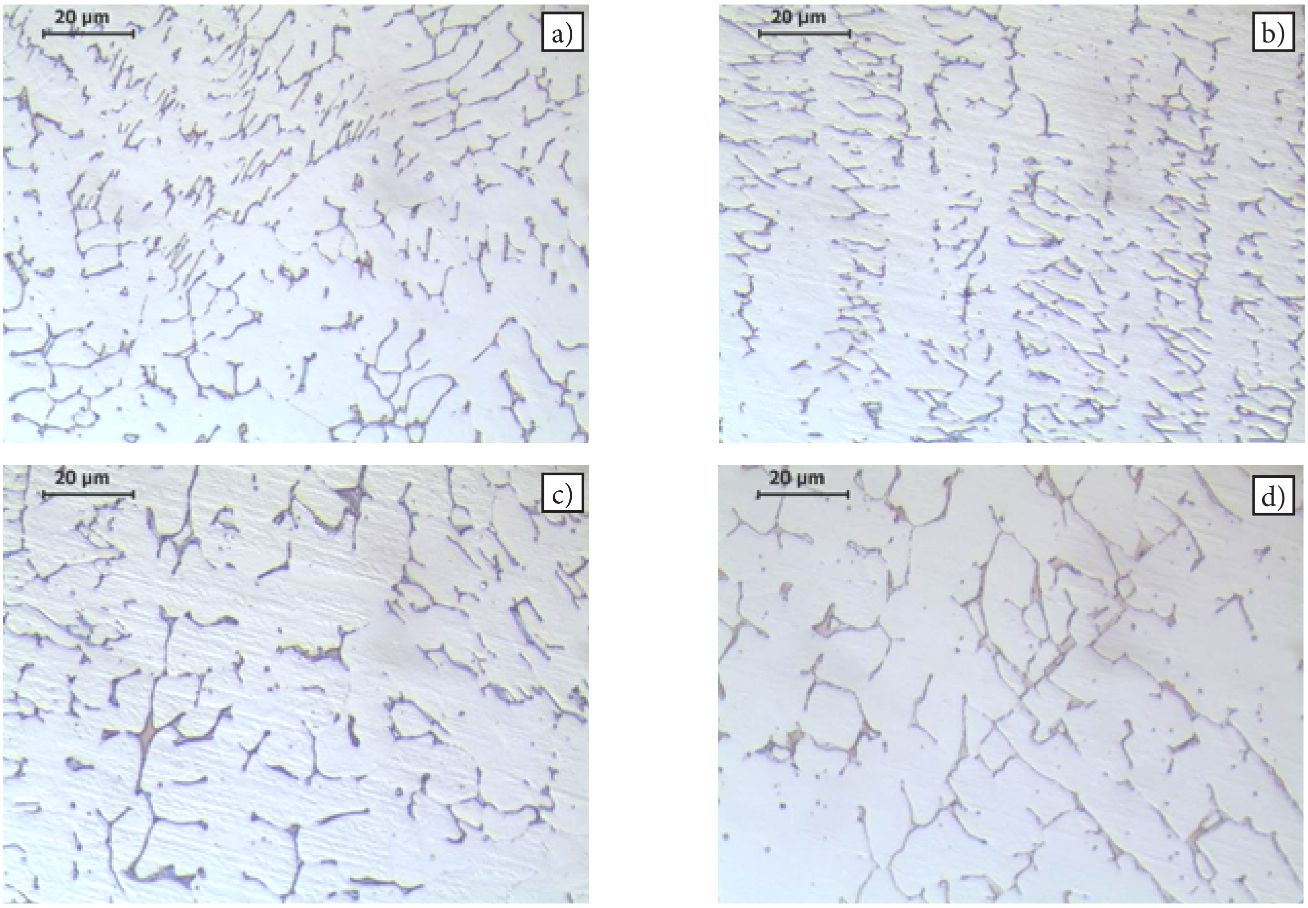

Fig. 5. Microstructure of specimen 1 – base material X6CrNi25-20: a) layer 1, b) layer 2, c) layer 3 and d) layer 4

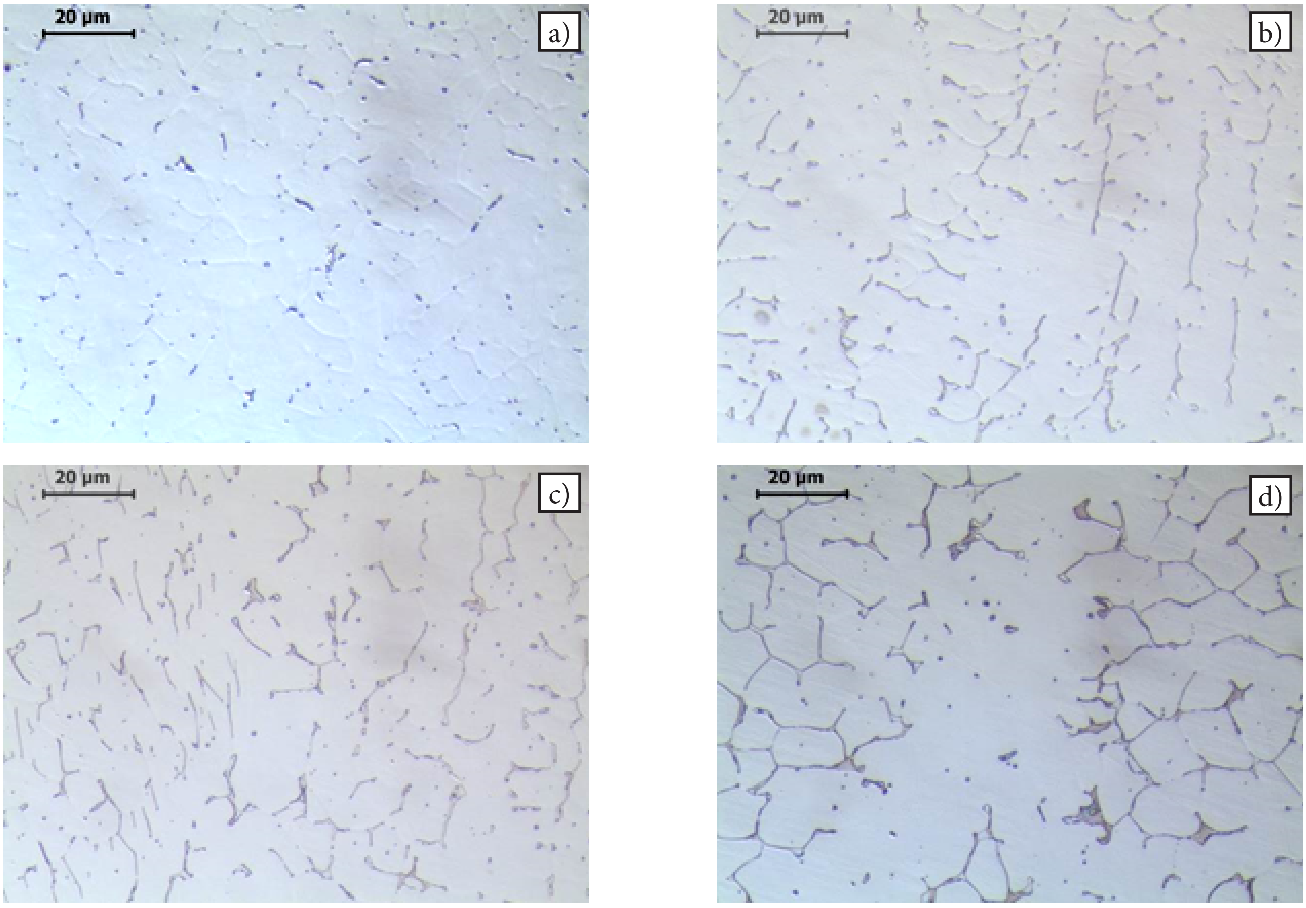

Fig. 6. Microstructure of specimen 2 – base material S235JR: a) layer 1, b) layer 2, c) layer 3 and d) layer 4

specimen 2, in layers 1 and 2, the amount of ferrite-δ was relatively low, yet its content grew along in successive layers. The microstructure of layer 4 in both specimens was similar.

The results of the chemical composition analysis are presented in Figures 7 and 8. Because of the maladjusted chemical composition of the base materials and of the filler metals, it was possible to observe the effect of the chemical composition of the base materials on the chemical compositions of the first 3-4 layers. In specimen 1, the base material of steel X6CrNi25-20 was characterised by higher contents of nickel and chromium and the lower content of manganese than those of filler metal G 18 8 Mn. In specimen 2, the base material of steel S235 was characterised by lower contents of chromium, nickel and manganese in comparison with that of filler metal G 18 8 Mn. The penetration into the base material during the making of the first layer (Fig. 3) resulted in the dilution of both materials and the obtainment of a material characterised by the intermediate chemical composition. A similar situation could be observed in subsequent layers, which, by

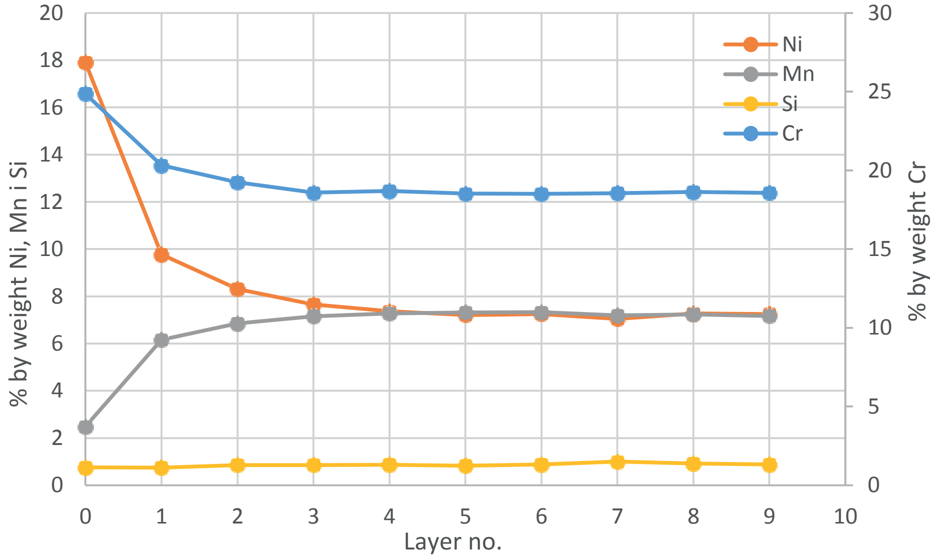

Fig. 7. Changes of contents (%) of chemical elements in the individual layers. Specimen 1 – base material X6CrNi25-20, layer 0 – base material

penetrating the previous layers, were responsible for the partial melting of the latter and allowed the weld pool to be supplied with a material characterised by a different chemical composition. The chemical composition became similar only in layers 4-5.

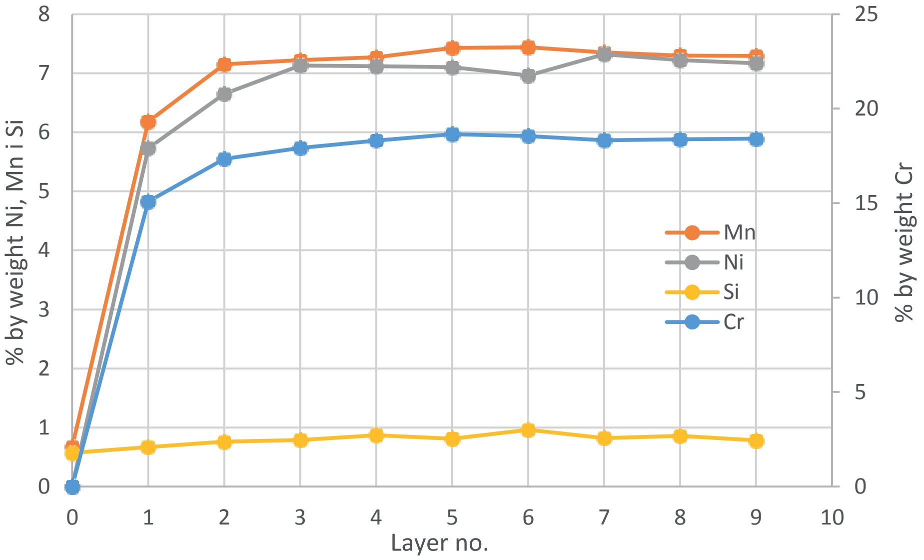

Fig. 8. Changes of contents (%) of chemical elements in the individual layers. Specimen 2 – base material S235JR, layer 0 – base material

## Summary

The above-presented macro and microanalyses as well as the chemical composition analysis revealed that the use of the maladjusted base material (in relation to the filler metal) was responsible for the fact that the chemical composition of the first layers of the additive manufactured products differed from the chemical composition of the filler metal weld deposit. The aforesaid phenomenon was connected with, first, the partial melting of the filler metal and, next, the partial melting of the previous layers (during the additive manufacturing process). Along with the deposition of the subsequent layers, the chemical composition was increasingly similar to that of the weld deposit declared by the filler metal manufacturer. The tests revealed the obtainment of the required chemical composition in the 4-th or 5-th layer. The results of the experiment confirm that the requirements of the ISO 6847 standard, stating that the chemical composition analysis should involve specimens sampled from the fifth layer (or higher) of weld deposit, are fully justified.

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