MICROSTRUCTURE AND MECHANICAL PROPERTIES OF G18-8-MN STAINLESS STEEL OBTAINED USING ELECTRON BEAM AND FOCUSED LASER RAPID PROTOTYPING METHODS

Łukasiewicz
Institute of Welding

Institute of Metallurgy
and Materials Science PAS

Politechnika Świętokrzyska
Kielce University of Technology

Łukasz Rogal[1], Marek St.Węglowski[2], Jan Dutkiewicz[1], Damian Kalita[1], Katarzyna Berent[2], Bogusz Kania[4], Bogdan Antoszewski[3], Hubert Danielewski[3], Sylwester Błacha[2], Krzysztof Kwieciński[2]
[1] Institute of Metallurgy and Materials Science, PAS, 25, Reymonta Str., 30-059 Krakow, Poland
[2] Łukasiewicz Research Network – Institute of Welding , 16-18, Bł. Czesława Str., Gliwice, Poland
[3] Kielce University of Technology, Laser Research Center, 25-314 Kielce, Poland
[4] Academic Centre for Materials and Nanotechnology, AGH, 30, Mickiewicza Av., Kraków, Poland

Introduction

Two various methods of rapid prototyping (RP) were used for deposition of stainless steel grade G18-8-Mn. The method of Electron Beam Additive Manufacturing (EBAM) used additive material in form of wire to form melt pool on surface of steel element by focused electron beam in vacuum [1]. In another, focused laser was applied to melt wire under protection of flowing Ar gas. Both RP methods enabled obtaining deposited layers on the S235 steel substrate. The EBAM deposited material of composition 0.07% - C, 7.1% - Mn, 0.8% -Si, 18.6%-Cr, 8.0% - Ni, Fe – balance consisted of mixture of austenite and ferrite (33 μm) in transition area with fine cell-dendritic microstructure, while large dendritic austenite grains were extended towards heat dissipation direction i.e. the substrate. Hardness $HV_{0.05}$ of the deposited material was in the range of 192-273 depending on distance from substrate. In the transition area of mixing with substrate, hardness reached 355 $HV_{0.05}$. Tensile strength was R_m = 720 MPa, $R_{0.2}$ = 574 MPa, ε = 25%. TEM studies of the area showed ε-martensite and high density of defects in austenite. Microstructure of laser deposited steel was similar to that observed in the EBAM prepared samples. Hardness of deposited material was 280 HV_{10} to 360 HV_{10} compared with 260 HV_{10} of the substrate. Heat flow from additive material in the central section of deposited material was dominated by thermal conductivity, while outside areas showed mixed mechanism of thermal convection and conductivity due to limitation of heat capacity. Tensile strength of the deposited material was R_m = 710 MPa, $R_{0.2}$ = 580 MPa, ε = 14%. Dendritic structure was observed in depositing material. Strain measurements using XRD method within transition austenite/ferrite area revealed that ferrite compressive stresses increased from substrate towards deposited material. In addition, higher mechanical properties of the interface area were connected with the appearance of martensite identified as ε-type typical for manganese steels, formed most probably due to predominant compressive stresses measured in the range of 500-600 MPa. In addition high defect density and a fine grain contributed to the higher strength as compared to the initial material.

MATERIALS PREPARATION

Electron Beam Rapid Prototyping

In the process of electron beam rapid prototyping involving the use of a filler metal wire, the filler (deposited) material (metal) is supplied to the liquid metal pool continuously provided with energy of the concentrated electron beam generated by the electron gun. The bombardment of the filler metal deposition area by the strongly focused electron beam within the range of 0.1 to 0.8 mm is responsible for the transformation of the kinetic energy of electrons into absorbed thermal energy melting the filler metal and base material (substrate). Technologically, the process of rapid prototyping involving the use of wire (filler metal) can be viewed as selective surfacing. The programing of a CNC machine enables the precise representation of a prefabricated element, whereas state-of-the-art equipment enables the precise adjustment of technological parameters. After being provided with filler metal wire feeder, a versatile electron beam welding device can be used in the process of rapid prototyping.

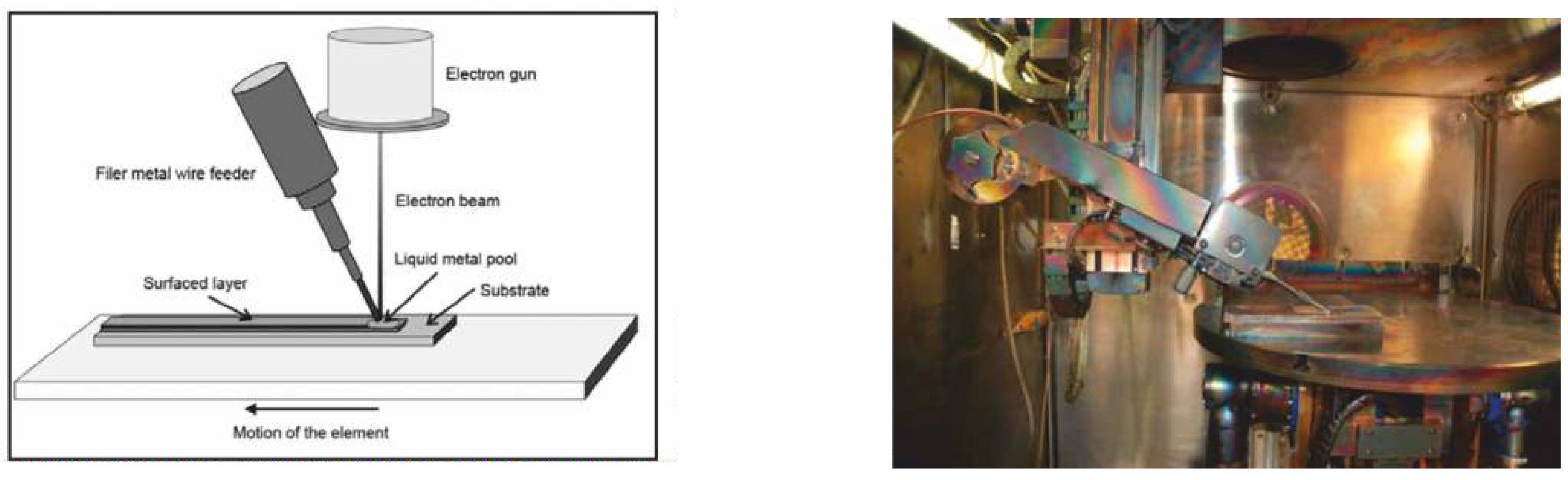

Fig. 1. Schematic diagram of electron beam rapid prototyping

Focused Laser Beam Rapid Prototyping

Process of laser rapid prototyping with filler wire as deposited material uses energy of focused photon beam which acts by melting additive material. Liquid metal appears as a result of beam effect on wire and base material surface creating metal pool. Melted wire deposited on base material crystallizes after laser heat source pass, forming padding weld. Deposition technology involving CO_2 laser requires output power exceeding 3kW. Range of process parameters for melting metal wire is wide, nevertheless developing padding weld with high aspect ratio requires numerous experimental research. Filler wire is supplied at angle of 45 degrees by feeder integrated with laser. Laser beam moving along programmed trajectory perform rapid prototyping. Deposited material in the form of filler wire as well as metal powder can be used In laser rapid prototyping.

Fig. 2. Schematic diagram of laser rapid prototyping

MICROSTRUCTURE AND MECHANICAL PROPERTIES ANALYSIS

ELECTRON BEAM

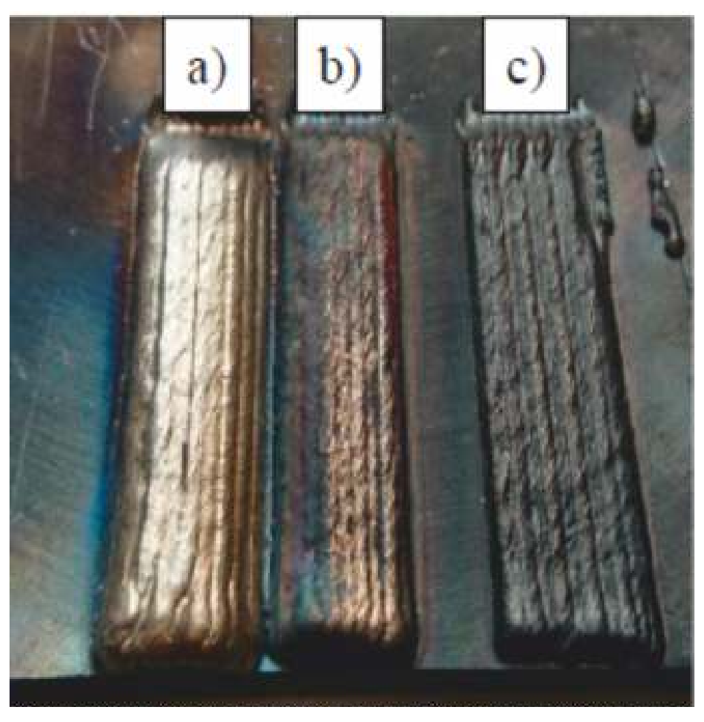

Fig. 3. EBAM parts, a) three layers, b) two layers c) single layer

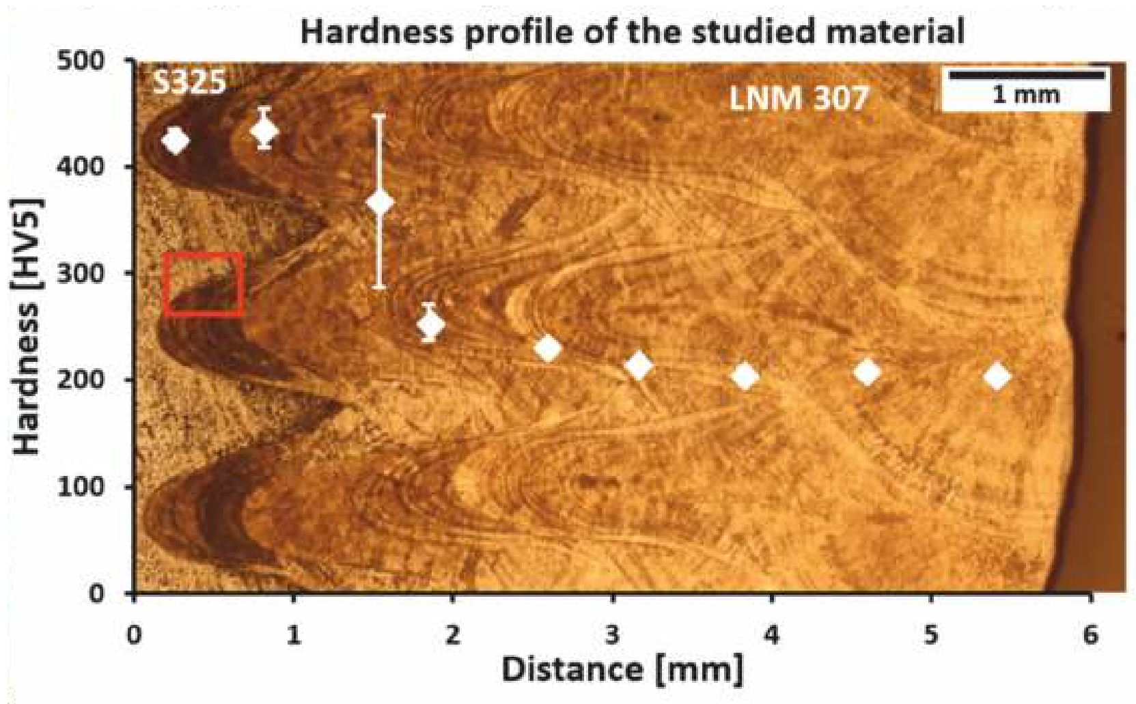

Fig. 4. Hardness profile of the EBAM part

The selection of technological parameters for AM was performed based on preliminary experimental trials as follows: accelerating voltage 60kV, beam current 15 mA, travelling speed 2000 mm/min, wire feed rate 1000 mm/min. The results indicated that too high penetration depth was applied. The penetration depth significantly exceeded the thickness of the deposited layers - the depth of the remelted zone was on average 4 mm at the layer thickness of 0.53 mm. The results indicated, that near the substrate the hardness was high (over 400HV5). However, at the distance of 2 mm the hardness became much lower (about 200 Hv5).

EBSD studies showed that microstructure after the process consisted of mixture of ferrite and austenite. Tensile tests were carried out on samples with a circular cross-section. LNM 307 after EBAM process showed yield strength 574 MPa at tensile strength 720 and plasticity 25%. Three phase structure of austenite, ferrite and martensite was responsible for an increase of strength

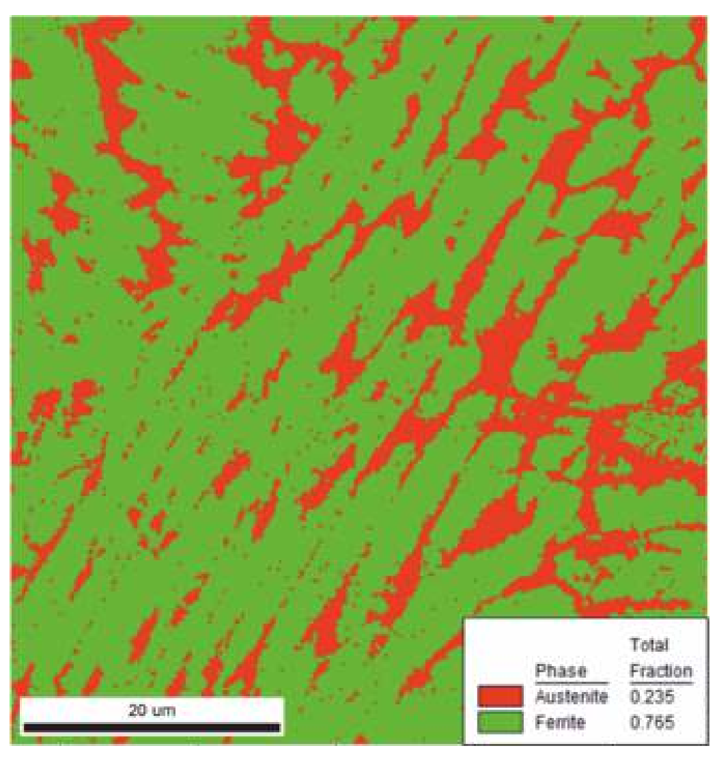

Fig. 5. EBSD analysis

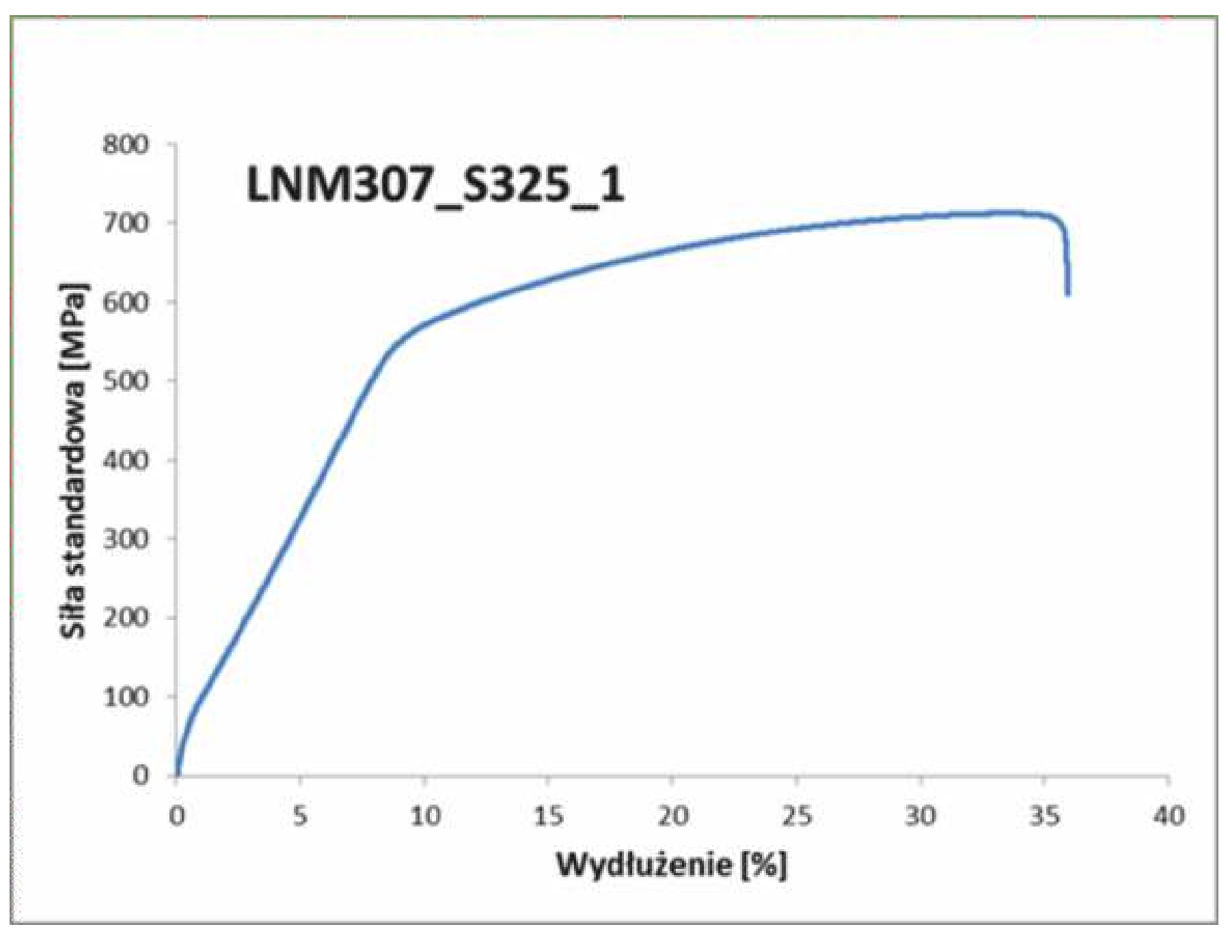

Fig. 6. Stress – strain curve, EBAM

LASER BEAM

Fig. 7. LBAM part

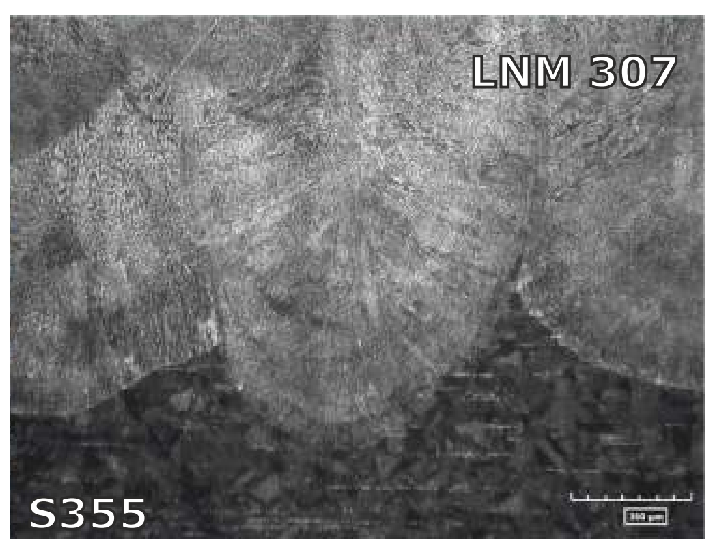

Fig. 8. Macrostructure of LBAM part – interlayer

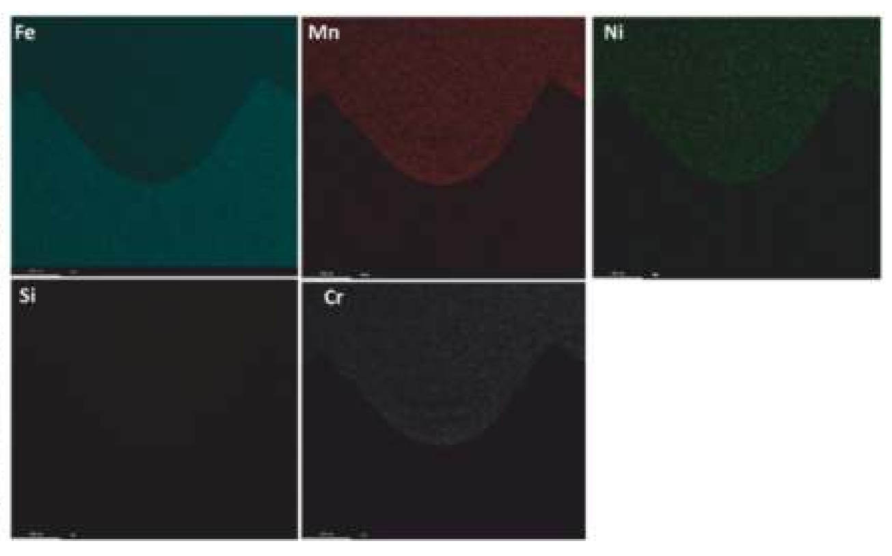

Fig. 9. Maps of element distribution, LBAM part

Mapping of element distribution from the interface area shows a high concentration of Ni, Cr, Mn, Si in the deposited material. No additional phases in the interface were observed.

Laser rapid prototyping parameters for achieved high aspect ratio was developed. Rectangular samples were produced applying following process parameters: laser output power=3300W, wire feed rate similar to feed speed=1500mm/min and wire of diameter 1.2mm. Rapid prototyping using CO_2 laser requires obtaining keyhole effect. Deep penetration of laser beam had an effect on deposited layer shape. In deposition process, substantial amount of thermal energy was absorbed in material causing local hardening. The highest hardness (370HV10) occurred in central area of padding weld, and it was greater than that of the base material (260HV10) most probably due to high cooling rate causing high defect density and a fine grain

Tensile strength test carried out on LNM 307 circular sample. Tensile strength of austenitic sample was 710MPa, similar to EB rapid prototyping, with plasticity 16%.

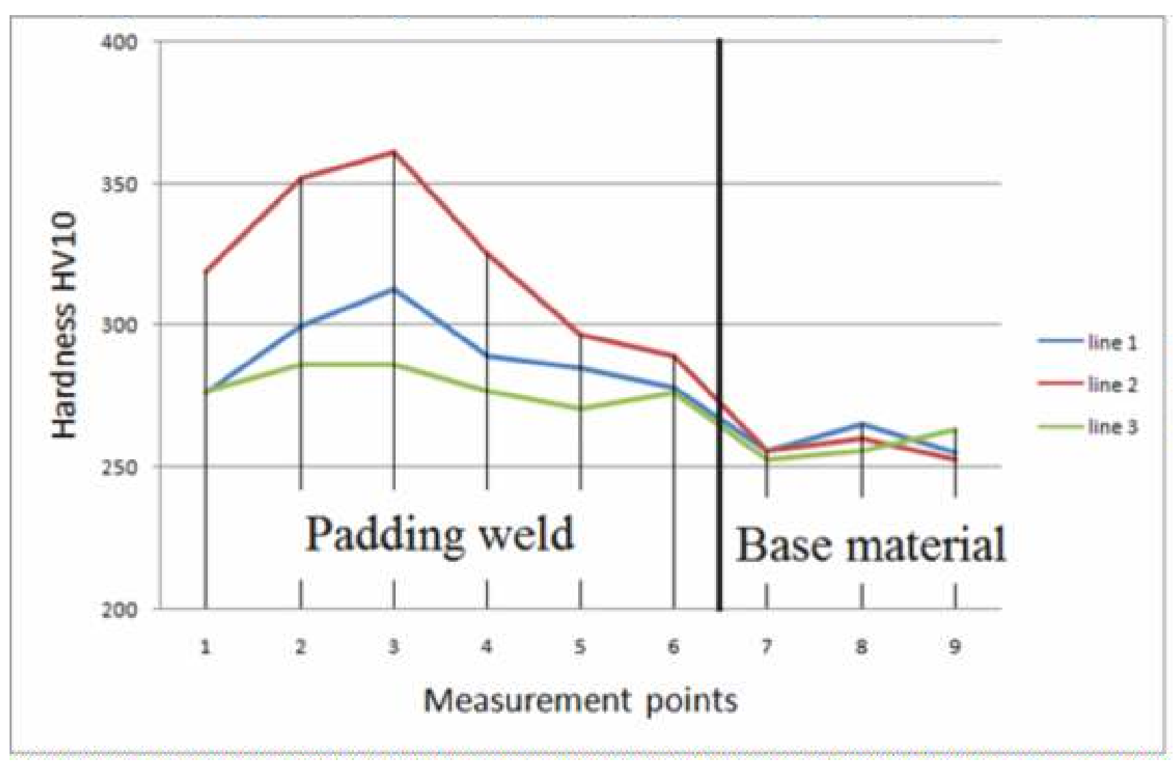

Fig. 10. Hardness profile of the LBAM part

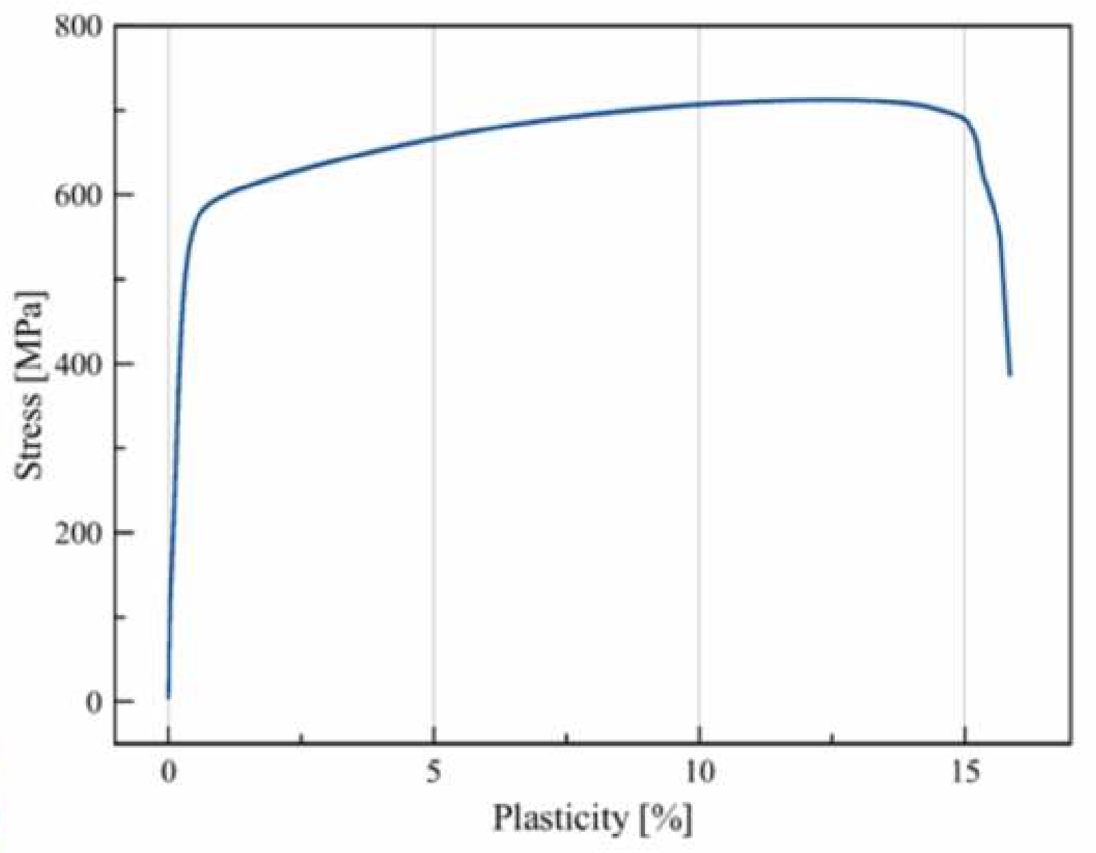

Fig. 11. Stress – strain curve, LBAM

Marek St. Węglowski Ph.D., Eng.
Łukasiewicz – Instititue of Welding
Bl. Czeslawa Str. 16-18
tel. +48 32 33 58 236
44-100 Gliwice
Marek.Weglowski@is.gliwice.pl

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