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UNCONVENTIONAL METHODS OF MANUFACTURING THIN WIRES FOR APPLICATION AS INPUT MATERIAL IN ADDITIVE MANUFACTURING. PART 1: PREPARATION OF INPUT MATERIAL FOR WIRE DRAWING

NIEKONWENCJONALNE METODY WYTWARZANIA CIENKICH DRUTÓW STALOWYCH DO ZASTOSOWANIA JAKO MATERIAŁ WSADOWY W TECHNOLOGIACH PRZYROSTOWYCH. CZĘŚĆ 1: PRZYGOTOWANIE WSADU DO CIĄGNIENIA DRUTÓW

Part 1 of the article presents the technological path of producing semi-finished products for wires constituting input material in additive technologies. On the basis of the developed chemical compositions of experimental Fe-based alloys, laboratory ingots with a square section of 120×120 mm / 130×130 mm were produced, which were then hot rolled into flat bars. In order to select the physical parameters of the drawing tests, numerical modelling of the process was performed. As a result of the simulations, it was found that the calculated drawing force exceeds the capabilities of the experimental drawing machine and for this reason, hydrostatic extrusion was used to produce bars intended for drawing wires. The hydrostatic extrusion method was used to make bars with a diameter of 5 mm from three tested materials, while three experimental steels showed insufficient susceptibility to extrusion at high pressure and cracked at various strain values. An analysis of possible causes of bar breakage during extrusion was carried out on the basis of the results of microstructure examination.

Keywords: *additive technology, wire, rolling, hydrostatic extrusion*

W części 1 artykułu przedstawiono ścieżkę technologiczną wykonania półwyrobów przeznaczonych na druty będące materiałem wsadowym do technologii przyrostowych. Na podstawie opracowanych składów chemicznych eksperymentalnych stopów na bazie Fe wytworzono wlewki laboratoryjne o przekroju kw. 120×120 mm / 130×130 mm, które następnie poddano walcowaniu na gorąco na płaskowniki. W celu dobrania parametrów fizycznych testów ciągnienia wykonano modelowanie numeryczne tego procesu. W wyniku symulacji ustalono, że wyliczona siła ciągnienia przewyższa możliwości eksperymentalnej ciągarki i z tego powodu do wytworzenia prętów przeznaczonych do ciągnienia drutów zastosowano wyciskanie hydrostatyczne. Metodą wyciskania hydrostatycznego wykonano pręty o średnicy 5 mm z trzech badanych materiałów, natomiast trzy eksperymentalne stale wykazały niewystarczającą podatność do wyciskania z wysokim ciśnieniem i ulegały pękaniu przy różnych wartościach odkształcenia. Przeprowadzono analizę możliwych przyczyn pękania prętów w trakcie wyciskania na podstawie wyników badań mikrostruktury.

Słowa kluczowe: *technologia przyrostowa, drut, walcowanie, wyciskanie hydrostatyczne*

1. INTRODUCTION

Additive manufacturing (AM) technologies for the production of structural components and final products from metals and metal alloys include several methods that differ in the technique of adding liquid portions of metal alloys to successive layers of the product. According to the classification and ter-

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minology established in ISO/ASTM 52900: 2015/2021, two main methods are defined that cover the many varieties of AM technology [1–4]:

- Directed Energy Deposition (DED) / adding material with a focused energy beam of continuously fed material. In the DED method, the starting material (powder or wire) is fed to a pool of liquid metal molten using a laser beam, electron beam or electric arc, to melt one stitch after another, and then layer by layer of the fabricated object.
- Powder Bed Fusion (PBF) / melting of an applied powder layer. The PBF method consists in spreading successive thin layers of powder over the entire cross-section of the formed object and melting successive layers one on top of the other using a laser beam or an electron beam.

Powders and wires are used as input materials for the AM-DED technology, and powders are used for the AM-PBF technology. The average particle diameter of the powders is in the range of 10–60 μm, while the wire diameters are equal to and less than 1 mm, often less than 0.8 mm.

Metal alloys are suitable for use in AM technologies, from which input semi-finished products with the required parameters can be produced – powders, wires or, less frequently, strips, characterised by good printability. The alloys suitable for additive processing should be characterised by the following features [2, 5, 6]:

– no tendency to crack during solidification and cooling after solidification under very high cooling rates,
– high ability to absorb thermal energy,
– ease of forming a homogeneous liquid solution during short-term melting,
– lack or little tendency to segregate elements in the solidification process,
– acceptable changes in the final chemical composition in relation to the composition of the input material, which may occur as a result of the evaporation of alloying elements,
– possibility to obtain the required properties immediately after the AM process.

The aim of the article – published in two parts – is to present the technological path covering the production of laboratory melts and the production of semi-finished products and final products in the form of wires with a diameter of 1.0 mm intended as an input material for additive technologies. The study was carried out as part of project No. 410049 (Techmatstrateg 2): "*Modern iron-based and copper-based alloys intended for the production of products with a designed structure and properties using additive technologies (MAT4AMT).*" Part 1 of the article presents the technological process from the stage of steel smelting to the production of bars with a diameter of 5 mm.

2. STUDIED MATERIALS

In order to achieve the properties of products manufactured using the AM methods assumed in the MAT4AMT project, the chemical compositions of Fe-based alloys were developed, and then laborato-

Table 1. Chemical compositions of experimental iron-based materials for the production of input material for wires

Tabela 1. Składy chemiczne eksperymentalnych materiałów na bazie żelaza przeznaczonych do wytwarzania wsadów na druty

Steel grade melt No.	Nom. Analysis	Element content [wt%]												
		C	Mn	Si	P	S	Ni	Cr	Co	Mo	V	Ti	Cu	Al
25H2N4MA S767	Nom.	0.21 0.28	0.25 0.55	0.17 0.37	max 0.030	max 0.025	4.00 4.40	1.35 1.65	–	0.30 0.40	–	–	max 0.20	0.01 0.02
	Analysis	**0.21**	**0.39**	**0.25**	**0.005**	0.005	4.01	1.37		0.33	0.21			**0.01**
MS350 S769	Nom.	max 0.015	max 0.10	max 0.15	max 0.010	max 0.010	18.0 19.0	–	12.0 12.5	4.8 5.2	-	1.3 1.6	max 0.05	0.04 0.08
	Analysis	**0.013**	**0.07**	**0.06**	**<0.01**	<0.01	18.6		**12.1**	**4.9**	-	**1.39**	**<0.02**	**0.09**
10N8M2Al S772	Nom.	0.08 0.12	max 0.10	max 0.15	max 0.010	max 0.005	8.3 8.7	-	–	1.8 2.1	-	–	–	1.2 1.5
	Analysis	**0.12**	**0.07**	<0.05	0.010	<0.01	8.4			2.0				**1.4**
10MFTi S775	Nom.	0.08 0.12	1.7 1.9	max 0.25	max 0.015	max 0.010	--	0.30 0.50	–	0.20 0.40	0.06 0.08	0.008 0.012	-	0.015 0.025
	Analysis	**0.11**	1.8	0.05	0.005	0.005		0.41		0.29	0.07	0.010		**0.035**
Fe-7Al S778	Nom.	max 0.015	max 0.10	max 0.15	max 0.010	max 0.005	–	–	–	–	–	–	–	7.0 7.5
	Analysis	**0.033**	**0.10**	**<0.1**	**<0.01**	**<0.01**								**7.6**
NANOS-BA 860492	Nom.	0.55 0.60	2.00 2.15	1.80 1.95	max 0.010	max 0.010	–	1.28 1.40	–	0.70 0.80	0.09 0.12	0.015 0.025	–	0.015 0.025
	Analysis	0.55	1.95	1.82	0.011	0.004		1.29		0.72	0.10	0.009		0.023

Nom. – required average nominal composition, Analysis – results of chemical analysis of the produced material, NANOS-BA – industrial melt material ry melts were made and ingots with a cross-section of 120×120 mm / 130×130 mm were cast. In total, 13 steel melts with different chemical compositions were obtained for the production of powder or wire, i.e. semi-finished products for additive manufacturing. The smelting and casting were carried out in a VSG100S vacuum induction furnace, which is a module of the line for semi-industrial physical simulation of industrial processes at Łukasiewicz – IMŻ. The ingots were the starting material for processing by forging and hot rolling to make bars for the production of powder with the spraying process and for the production of wires. Table 1 summarises the chemical compositions of materials intended for the production of input material for wires. In the class of structural alloy steels, the currently used grade 25H2N4MA, as a reference material, and an experimental 10MFTi micro-alloy steel grade were prepared for testing. In the group of maraging steels, the classic MS350 grade was melted and the experimental 8% Ni maraging steel was melted – with a significantly reduced content of alloying elements – 10N8M2Al. The experimental Fe-7Al alloy represents steels with decreased density based on the Fe-Al system. The NANOS-BA® steel is a new ultra-durable material with a nanobainitic structure, developed and improved at Łukasiewicz – IMŻ [7].

Before hot working, 25H2N4MA (S767), MS350 (S769), 10N8M2Al (S772) and 10MFTi (S775) steel ingots were subjected to homogenisation annealing at 1250 °C for 24 hours in a furnace chamber with restricted air access. The NANOS-BA steel semi-finished products were homogenised in industrial conditions and then milled to remove surface defects. Fig. 1 presents photographs of the ingots after annealing (a) and milling (b).

3. TECHNOLOGY OF MANUFACTURING SEMI-FINISHED PRODUCTS INTENDED FOR WIRES AS THE INPUT MATERIAL FOR ADDITIVE TECHNOLOGIES

3.1. ASSUMPTIONS FOR THE DEVELOPMENT OF PRODUCTION TECHNOLOGY FOR WIRES AS INPUT MATERIAL FOR ADDITIVE TECHNOLOGIES

In order to obtain wires from wires intended for input material for additive technologies, the technological process was divided into the following plastic and heat treatment operations [8]:

1. Hot rolling of ingots into semi-finished products in the form of bars or flat bars.
2. Longitudinal cutting of the obtained semi-finished products.
3. Machining of semi-finished products to obtain round or square bars.
4. Heat treatment of bars to produce a microstructure improving cold formability.
5. Extrusion or drawing of bars.
6. Interoperational heat treatment to remove the effects of strain hardening.
7. Drawing of bars to the final size of ϕ1.0 mm.

Fig. 1. Photographs of laboratory ingots after homogenisation annealing (a) and surface milling (b)

Rys. 1. Fotografie wlewków laboratoryjnych po wyżarzaniu ujednorodniającym (a) i po frezowaniu powierzchniowym (b)

3.2. TECHNOLOGY OF HOT ROLLING OF STEEL FLAT BARS INTENDED FOR MATERIALS FOR ADDITIVE MANUFACTURING

The material for rolling consisted of ingots with the chemical composition presented in Table 1. The heating temperature for rolling of individual steel grades was selected based on their chemical composition and the forecast plastic properties in terms of hot plastic working temperature, taking into account the requirements for the properties of the final product. The ingots and individual strips with intermediate thicknesses were heated for rolling in an electric heating furnace of an LPS-B line for semi-industrial process simulation [9]. The heating temperature for plastic working of the input material made of the Fe-7Al alloy was 1150°C, while the remaining materials were heated to 1220°C. The input material's annealing time depended on the cross-section of the material, and in the case of an ingot with a cross-section of 123×113 mm it was 120 minutes, while for the intermediate 23 mm thick strip it was 20 minutes. During feeding, the input material was placed on the hearth of the furnace in such a way that it could be evenly heated. Hot plastic processing of the ingots was performed in the LPS-B line, using a single-frame reversible double-roller rolling mill with a roller diameter of 550 mm and a barrel length of 700 mm. The ingots were rolled in a few stages to their final nominal thickness of 17 mm (Fig. 2).

4. NUMERICAL MODELLING OF THE BAR DRAWING PROCESS

In order to select the physical parameters of the drawing tests, numerical modelling of the process was performed using the Qform3D program [10]. The studies included: deformation intensity distributions on the cross-section, temperature distribution and the force necessary to draw the bars. Fig. 3 shows the distribution of drawing forces during the deforma-

Fig. 2. Photograph of flat bars from the tested materials after rolling in LPS-B into strips with a final thickness of approx. 17 mm

Rys. 2. Fotografia przykładowych płaskowników z badanych materiałów po walcowaniu w LPS-B na pasma o grubości końcowej ok. 17 mm

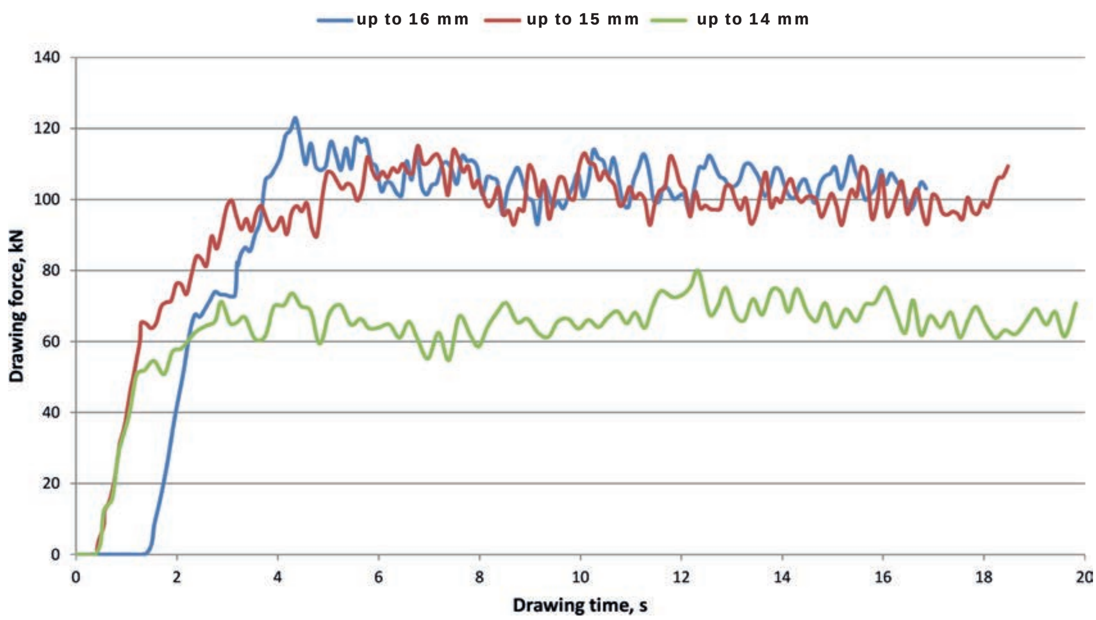

Fig. 3. Drawing forces of MS350 steel bars with a 12 % draft

Rys. 3. Siły ciągnienia prętów ze stali MS350 z gniotem ok. 12 %

tion of bars with the planned draft of approx. 12 %, which is typical for drawing hard-deforming steels [11–13], in three variants:
a) ϕ16 mm bar drawn to ϕ15 mm,
b) ϕ15 mm bar drawn to ϕ14 mm,
c) ϕ14 mm bar drawn to ϕ13.1 mm.

As a result of the simulations, it was found that the calculated drawing force of maraging steel bars with a diameter of 16 mm and 15 mm exceeds the capabilities of a draw bench that is a module of the semi-industrial LPS line at Łukasiewicz – IMŻ, the maximum tension force of which is 100 kN (Fig. 3). The calculated drawing forces show that it is possible to draw bars with an initial diameter of approx. 14 mm.

5. PRODUCTION OF BARS FOR DRAWING FROM HOT ROLLED FLAT BARS

The framework technology assumed the production of round bars for drawing using machining. Based on the experience from study [14], it was found that it is possible to produce bars with a length of approx. 500 mm and a diameter of 16 mm using this method. The technical parameters of the draw bench enable the drawing of bars with a minimum length of approx. 400 mm and a maximum diameter of 14 mm. Reducing the diameter of the bars to the value of 14 mm, i.e. to the maximum diameter possible to draw in the LPS draw bench, was not possible due to the section of the bar after turning being too short, i.e. below 400 mm. It is caused by technical limitations – as the diameter of the bar is reduced, the maximum possible length of the bar is also reduced, due to the need to maintain rolling stability. For the presented reasons, the process of hydrostatic extrusion, instead of drawing, was used as a method of cold plastic working of bars with the above-mentioned diameters.

6. HYDROSTATIC EXTRUSION OF BARS

As an alternative method of deformation to the drawing of bars with a diameter of 15–16 mm, hydrostatic extrusion of bars with a diameter of 19–20 mm was used. Unipress-Extrusion was commissioned to perform tests to verify the feasibility of using hydrostatic extrusion methods and then rotational forging of 1 mm diameter wire made of the MS350, 10N8M2Al, 25H2N4MA, 10MFTi, Fe-7Al and NANOS-BA maraging steel [15]. As a result of the tests, it was found that the smallest possible diameter that can be obtained using the method of hydrostatic extrusion and subsequent rotary forging is approx. 3 mm. Thus, it is not possible to achieve the diameter of the wire used as

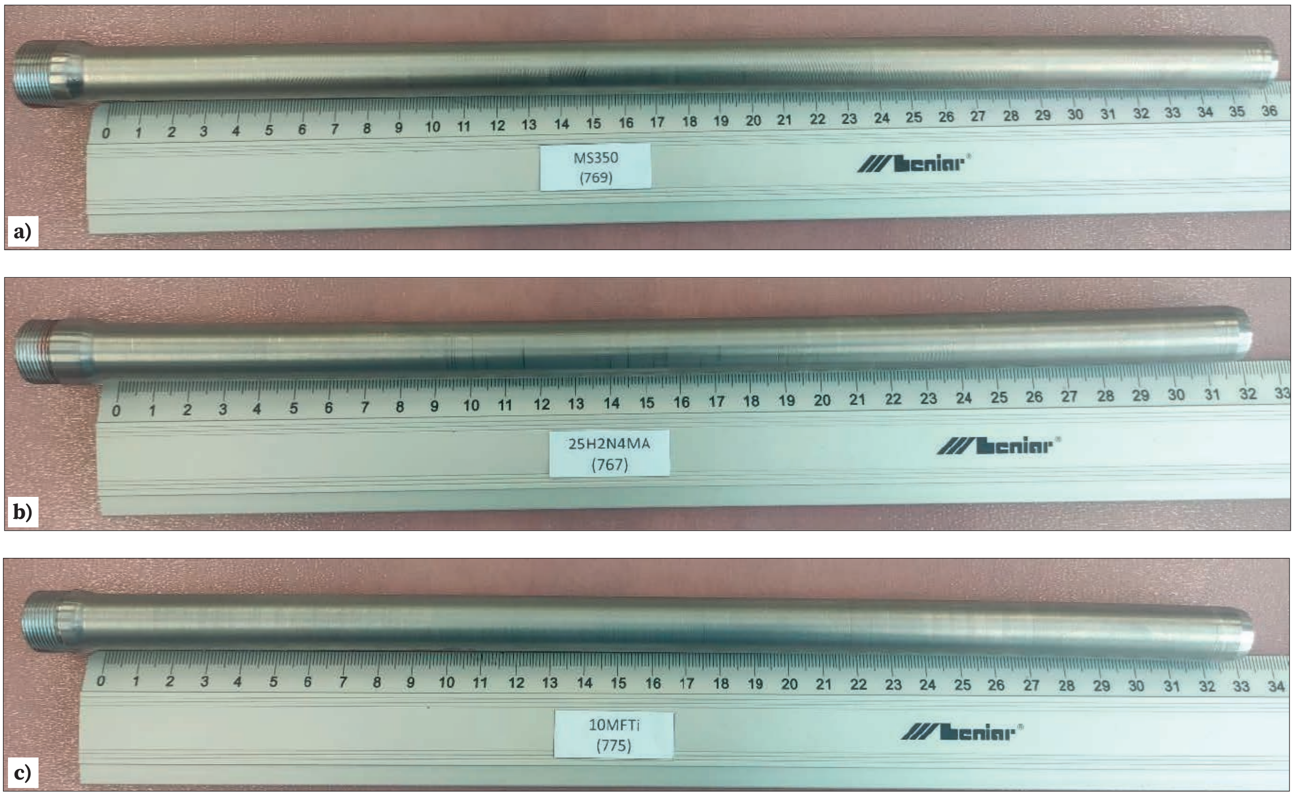

Fig. 4. Bars with a diameter of approx. 5 mm obtained using the hydrostatic extrusion method. a) MS350 steel after extrusion with real total strain ε = 2.74; b) 25H2N4MA steel after extrusion with real total strain ε = 2.64; c) 10MFTi steel after extrusion with real total strain ε = 2.64 [15]

Rys. 4. Pręty o średnicy ok. 5 mm uzyskane metodą wyciskania hydrostatycznego: a) stal MS350 po wyciskaniu z rzeczywistym odkształceniem całkowitym ε = 2,74; b) stal 25H2N4MA po wyciskaniu z rzeczywistym odkształceniem całkowitym ε = 2,64; c) stal 10MFTi po wyciskaniu z rzeczywistym odkształceniem całkowitym ε = 2,64 [15]

input material for the WAAM technologies with these methods, but it is possible to produce a semi-finished product for the final drawing operation. The results of the rotary forging tests for the studied materials are not the subject of this paper.

Based on the results of hydrostatic extrusion tests, it was found that not all tested materials showed good cold deformability with the required large actual strain values. The hydrostatic extrusion method was used to produce bars without material defects, with a minimum diameter of approx. 5 mm, made of MS350, 25H2N4MA and 10MFTi maraging steels (Fig. 4) [15]. Bars made of the remaining steels cracked at various strain values. NANOS-BA steel bars cracked at strain ε = 0.34 (Fig. 5). A bar made of Fe-7Al steel, even at a relatively low extrusion pressure of 520 MPa, was subject to periodic fragmentation in the deformation zone in the die (Fig. 6). The 10N8M2Al steel was subjected to the process of cumulative hydrostatic extrusion with a total real strain ε = 1.53, as a result of which a bar with a diameter of 8 mm without defects and surface damage (Fig.7a) was obtained. Increasing the cumulative strain in the

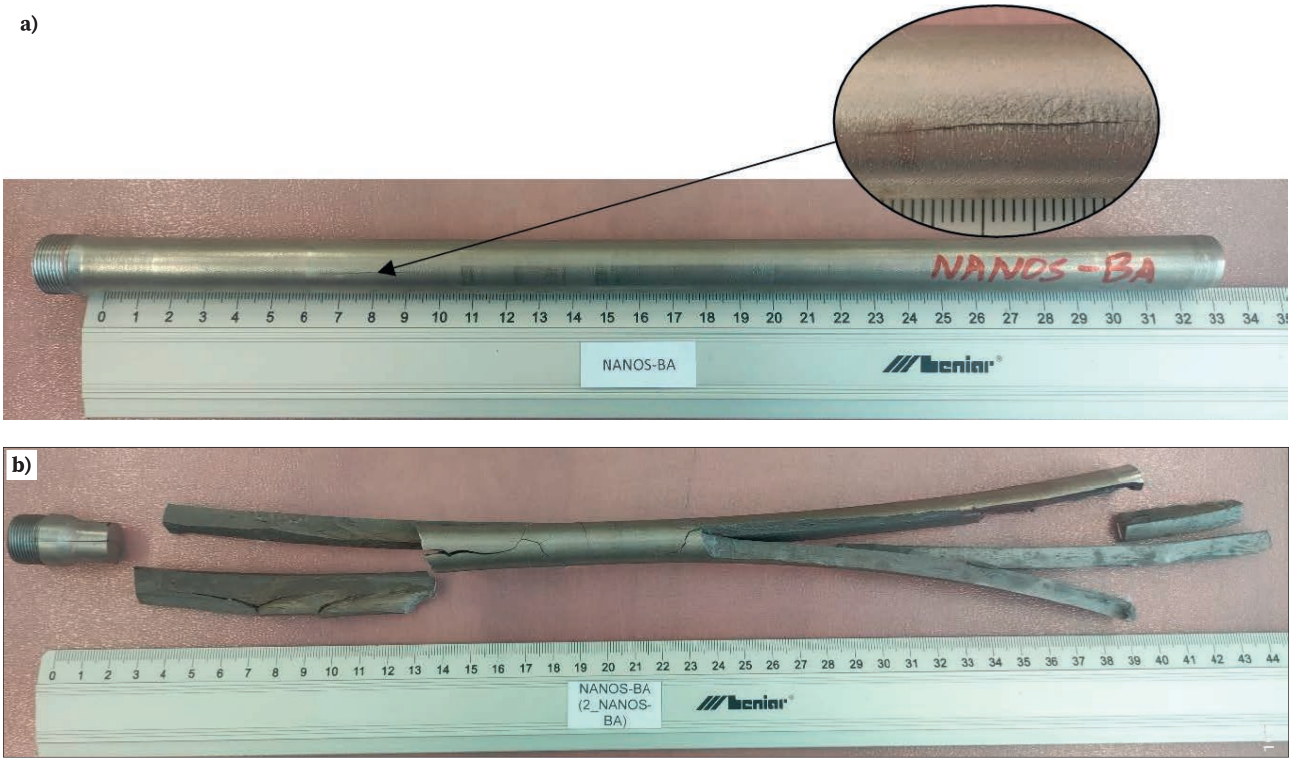

Fig. 5. NANOS-BA steel bars after hydrostatic extrusion: a) initial trial with strain ε = 0.34; b) trial with increased rate of the extruder shaft, with strain ε = 0.34 [15]

Rys. 5. Pręty ze stali NANOS-BA po wyciskaniu hydrostatycznym: a) próba wstępna z odkształceniem ε = 0,34; b) próba ze zwiększoną prędkością tłoka wyciskającego, z odkształceniem ε = 0,34 [15]

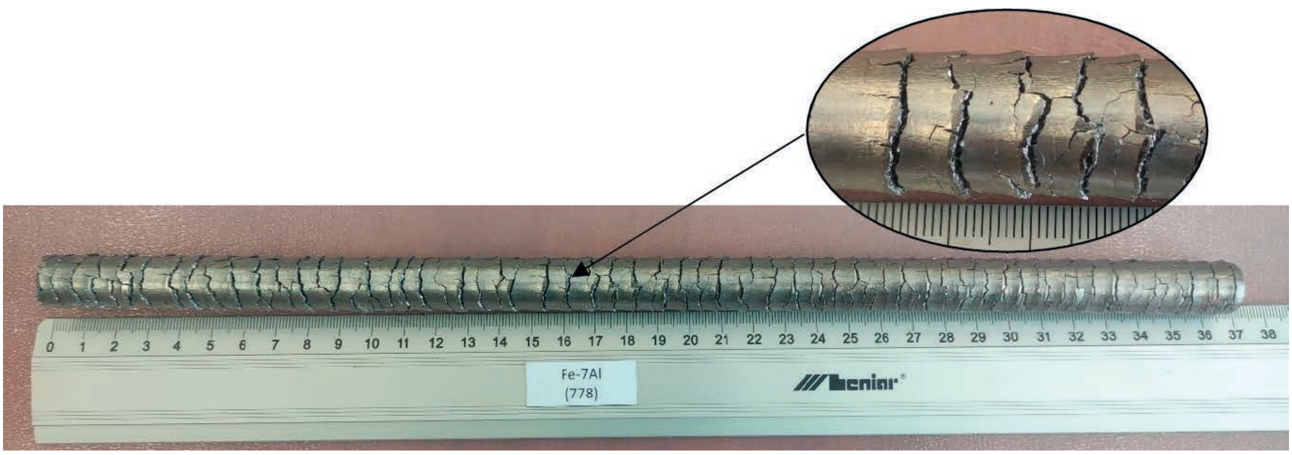

Fig. 6. Fe-7Al steel bar after hydrostatic extrusion with strain ε = 0.44 [15]

Rys. 6. Pręt ze stali Fe-7Al po wyciskaniu hydrostatycznym z odkształceniem ε = 0,44 [15]

Fig. 7. 10N8M2Al steel bars after hydrostatic extrusion with strain a) ε = 1.53, b) ε = 1.8 [15]

Rys. 7. Pręty ze stali 10N8M2Al po wyciskaniu hydrostatycznym z odkształceniem a) ε = 1,53, b) ε = 1,8 [15]

fourth stage of the hydrostatic extrusion process led to the fragmentation of the extruded bar (Fig. 7b).

Based on the results of deformation tests, the method of cold hydrostatic extrusion was selected to produce bars with a diameter of 5 mm from MS350, 25H2N4MA and 10MFTi maraging steels (with the possibility of reducing the diameter by rotary forging), which will be the input material for drawing wires with a diameter of 1 mm.

7. ANALYSIS OF BAR MICROSTRUCTURE AFTER HYDROSTATIC EXTRUSION TESTS

The materials on which hydrostatic extrusion tests were performed are not intended for industrial cold forming and therefore standard heat treatment parameters are not available to obtain a microstructure suitable for this procedure. The parameters of heat treatment increasing the susceptibility to cold deformation of the tested materials were developed on the basis of currently available knowledge and based on the results of microstructure, hardness and mechanical properties studies, obtained after various variants of heat treatment. After experimental verification using cold deformation methods, these parameters are optimised. The effects for the successive values of deformation using the method of hydrostatic extrusion are presented in Chapter 6. After the extrusion tests, bars with a diameter of 5 mm without material defects were obtained from the MS350, 10N8M2Al, 25H2N4MA and 10MFTi steels, while bars made of the NANOS-BA, 10N8M2Al and Fe-7Al materials cracked at various stages of extrusion.

In order to obtain increased plasticity of the NANOS-BA nanobainite steel in cold deformation processes, it is necessary to obtain a microstructure susceptible to deformation, which is fine-plate pearlite or spheroidite. The aim of the treatment of the NANOS-BA steel prior to the cold hydrostatic extrusion tests was to obtain a single-phase pearlitic microstructure. After the treatment, apart from pearlite, islands were formed with a structure consisting mainly of high-carbon martensite and bainite (Fig. 8a), which are the cause of reduced plasticity, leading to cracking in the extrusion process (Fig. 8b). In the course of further tests of cold deformability of nanobainite steels, in order to increase plasticity, a spheroidite structure consisting of recrystallised ferritic matrix and fine carbide particles should be obtained in the initial state.

The likely cause of the insufficient cold deformability of the 10N8M2Al maraging steel and bar cracking during extrusion tests (Fig. 9a) was the formation of initial microstructure containing a large fraction of various morphological forms of ferrite (Fig. 9b). Ferrite grains and plates are the nucleation sites for cracks during cold deformation. In order to produce a single-phase structure of dislocated lath martensite – as an optimal state before cold deformation of maraging steel – it is necessary to increase the cooling rate during solution heat treatment and/or modify the chemical composition of the 10N8M2Al steel to increase hardenability.

The complete lack of susceptibility to cold deformation using the extrusion method is characterised by the Fe-7Al alloy – with a reduced density compared to standard structural steels. The lack of sufficient cold plasticity results from the coarse-grained structure of the ferritic matrix (Fig. 10), a strong tendency of ferrite containing 7 % Al to strengthen, and the influence of κ carbide precipitates at grain and sub-grain boundaries. For further tests of producing wire from a low-density steel, the melting of the experimental duplex 19Mn10Al-0.6C steel was designed.

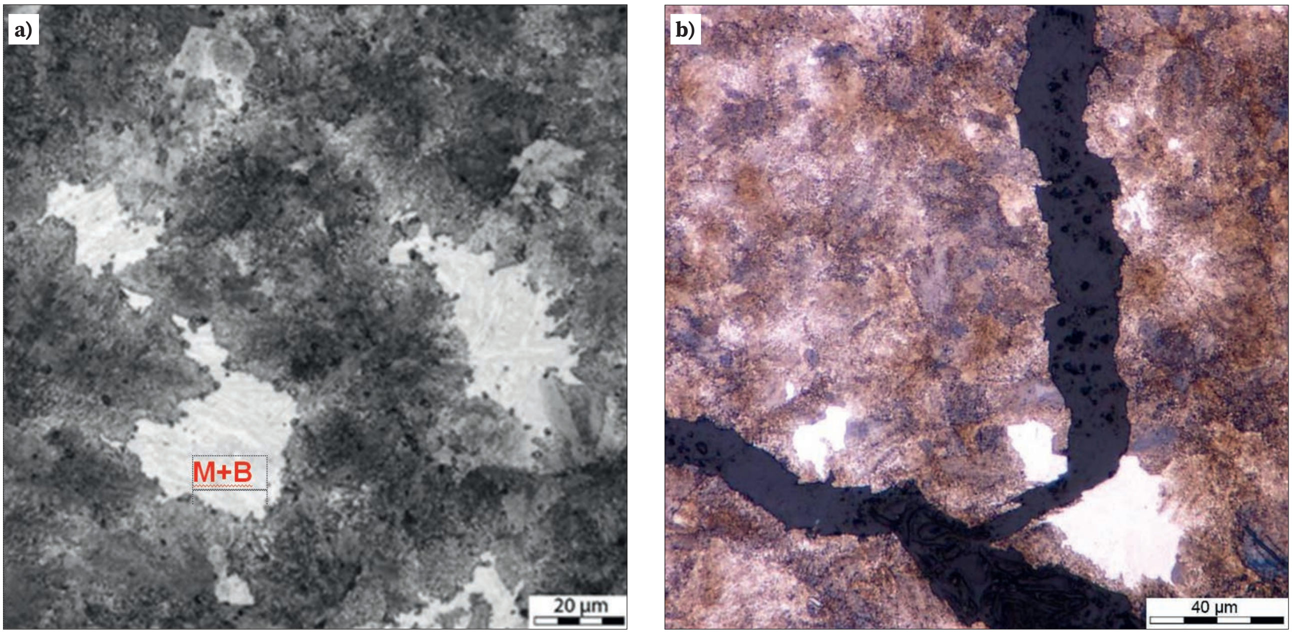

Fig. 8. a) Microstructure of input bar for hydrostatic extrusion tests of NANOS-BA steel after softening heat treatment, M + B – martensite-bainite islands, b) Cracks in a NANOS-BA steel bar after the cold hydrostatic extrusion step disintegrating the test material; images of microstructure obtained with a light microscope

Rys. 8. a) Mikrostruktura pręta wsadowego do prób wyciskania hydrostatycznego ze stali NANOS-BA po obróbce cieplnej zmiękczającej, M+B – wyspy martenzytyczno-bainityczne, b) Przykład pęknięć w pręcie ze stali NANOS-BA po etapie wyciskania hydrostatycznego na zimno powodującego dezintegrację badanego materiału; obrazy mikrostruktury uzyskane za pomocą mikroskopu świetlnego

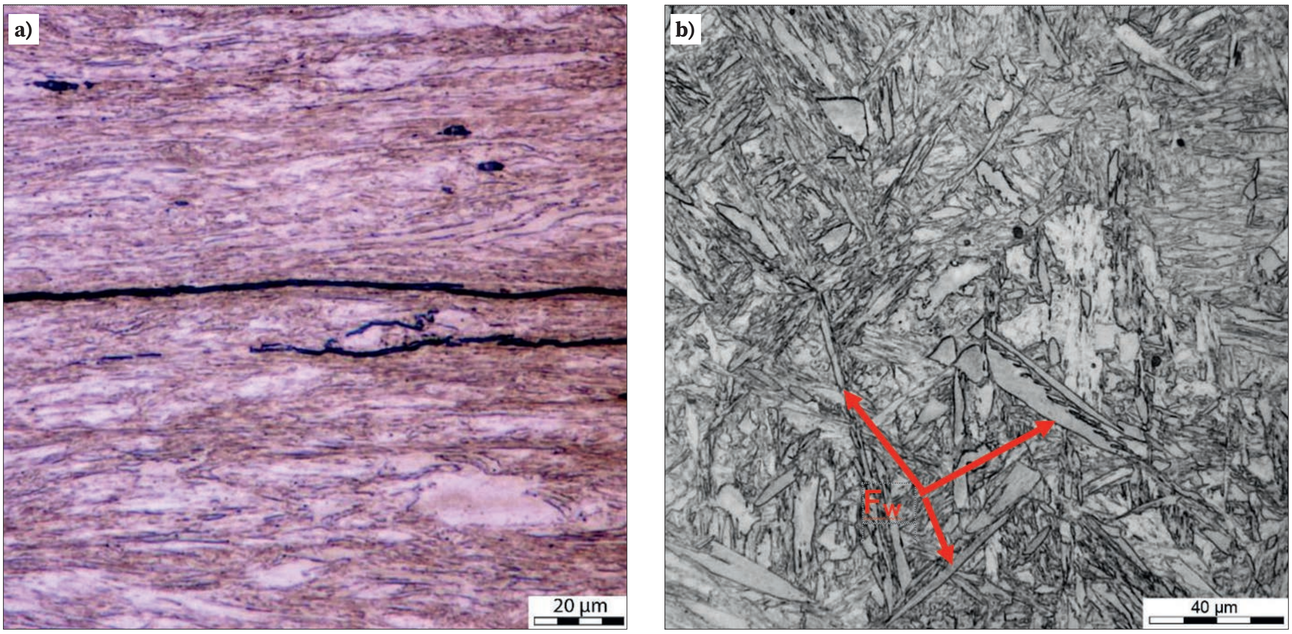

Fig. 9. a) Cracks in a 10N8M2Al steel bar after the stage of cold hydrostatic extrusion causing fragmentation of the bar – longitudinal section; b) Microstructure of a 10N8M2Al steel input rod for hydrostatic extrusion tests after solution heat treatment, F_W – Widmanstätten ferrite plates; images of microstructure obtained with a light microscope

Rys. 9. a) Przykład pęknięć w pręcie ze stali 10N8M2Al po etapie wyciskania hydrostatycznego na zimno powodującego fragmentację pręta – przekrój wzdłużny; b) Mikrostruktura pręta wsadowego do prób wyciskania hydrostatycznego ze stali 10N8M2Al po obróbce przesycającej, F_W – płytki ferrytu Widmanstättena; obrazy mikrostruktury uzyskane za pomocą mikroskopu świetlnego

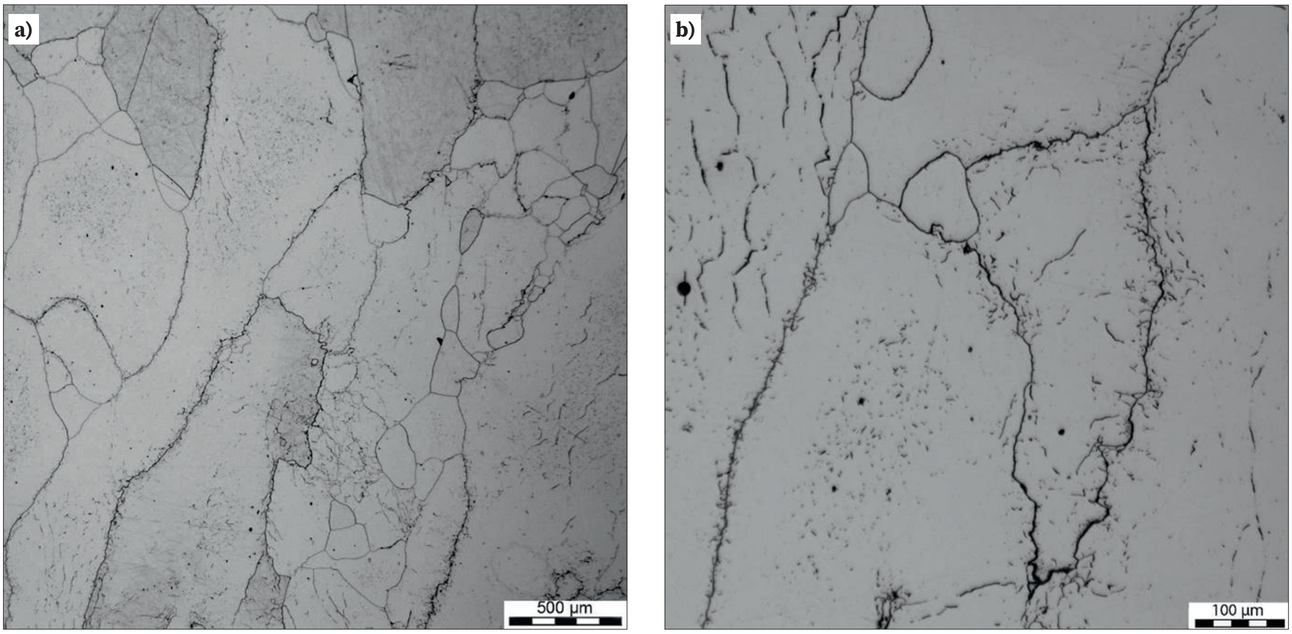

Fig. 10. Microstructure of input Fe-7Al steel bar for hydrostatic extrusion tests after softening treatment: a) longitudinal section, b) cross section; microstructure images obtained using a light microscope

Rys. 10. Mikrostruktura pręta wsadowego do prób wyciskania hydrostatycznego ze stali Fe-7Al po obróbce zmiękczającej: a) przekrój wzdłużny, b) przekrój poprzeczny; obrazy mikrostruktury uzyskane za pomocą mikroskopu świetlnego

8. SUMMARY AND CONCLUSIONS

Part 1 of the article presents the technological path of producing semi-finished products for wires to be used as input material in additive technologies. On the basis of the developed chemical compositions of Fe-based alloys, square 120×120 mm / 130×130 mm ingots were produced, which were then hot rolled into flat bars. The following materials were prepared for examination and tests: the currently used grade 25H2N4MA as a reference material, experimental microalloy 10MFTi steel, maraging MS350 steel, experimental maraging 10N8M2Al steel, Fe-7Al alloy with reduced density and ultra-high-strength NANOS-BA® nanobainite steel.

In order to select the physical parameters of the drawing tests, numerical modelling of the process was performed using the Qform3D program. As a result of the simulations, it was found that the calculated drawing force of bars made of some tested materials with a diameter of 15–16 mm exceeds the capabilities of the draw bench on which the tests were planned. As an alternative method of deformation to the drawing of bars with a diameter of 15–16 mm, hydrostatic extrusion of bars with a diameter of 19–20 mm was used.

Based on the results of the hydrostatic extrusion tests, it was found that the maraging MS350, 25H2N-4MA and 10MFTi materials, from which the bars with a diameter of 5 mm were made, showed good cold deformability with the required large real strain. Bars made of the remaining tested steels: NANOS-BA, 10N8M2Al and Fe-7Al, were cracking at various stages of extrusion.

The reason for the reduced plasticity of the NANOS-BA steel, leading to cracking in the extrusion process, was the initial microstructure containing islands consisting of high-carbon martensite and bainite. In the course of further tests of cold deformability of nanobainite steels, in order to increase plasticity, a spheroidite structure consisting of recrystallised ferritic matrix and fine carbide particles should be obtained in the initial state. The probable cause of the insufficient cold deformability of the 10N8M2Al steel was the morphology of the ferrite base microstructure, in which cracks develop during cold deformation. In order to obtain the optimal state of the microstructure before cold deformation – such as dislocated lath martensite – it is necessary to increase the cooling rate during the solution heat treatment procedure and/or increase the hardenability of the 10N8M2Al steel. The Fe-7Al alloy with reduced density is characterised by the lowest susceptibility to cold deformation in the group of tested materials. The low plasticity of the Fe-7Al alloy results from the coarse-grained structure of the ferritic matrix, a strong tendency of ferrite with a high content of Al to strengthen, and the influence of κ carbide precipitates at grain and sub-grain boundaries.

Part 2 of the article will present the process of drawing bars from selected steel grades, which are the subject of the research in part 1, intended for the production of a wire with a diameter of ϕ1.0 mm, which is an input material for additive technologies.

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