

Investigation of the Microstructure and Microhardness after Electron Beam Welding of AISI 316L Stainless Steel and LaserForm Maraging Steel

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Abstract—The present study is related to the implementation of Electron Beam Welding of 316L stainless steel blanks obtained by traditional methods of plastic deformation and a blank made of LaserForm Maraging Steel obtained by Additive manufacturing also known as 3D Metal Printing Technology. A microstructural analysis was performed using a Scanning Electron Microscopy (SEM). To determine the chemical distribution at the fusion zone (FZ) an energy dispersive spectroscopy (EDS) was used. Vickers microhardness distribution across the welded seam was investigated in two zones – the first one at 1 mm from the surface and the second one at 3 mm from the surface.

Keywords— *Electron beam welding, microstructure, microhardness.*

I. INTRODUCTION

The Electron Beam Welding (EBW) process is a Fusion Welding process as the metal to metal joint forms in liquid or molten state. This type of welding process is also classified as a new welding process as it uses the kinetic energy of fast-moving electrons to fuse two metal pieces at its joint [1].

The advantages of the process, as no edge preparation is necessary, the high welding speed results in narrow welds and heat affected zones with little distortion of the workpiece, short evacuating times can be achieved by adopting the working chamber to suit the number and size of workpieces, simple longitudinal weld seams can be welded as well as complicated three-dimensional components requiring use of programmed welding

parameters and workpiece manipulation [2] etc., make it applicable in Aerospace, Automotive, Defense, Semiconductor, Medical, Nuclear, Oil & Gas, Power Generation and a variety of other industries.

On the other hand Additive manufacturing (AM), also known as 3D printing, is a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. This tool less manufacturing approach can give industry new design flexibility, reduce energy use and shorten time to market. Main applications of additive manufacturing include rapid prototyping, rapid tooling, direct part production and part repairing of plastic, metal, ceramic and composite materials.

The 3d printing technology covering wide range of alloys used in a variety of industries (including aerospace, automotive, dental, jewelry, oil and gas, orthopedics printed electronics, and tooling) [3], [4], [5].

From the above, it is striking that both processes have the same application.

In various publications, data on the application of electron beam welding have been found as:

- technology for welding similar and dissimilar materials[1], [2], [6], [7], [21];
- application of coatings;

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- modification of the surface layer [8];
- Electron beam cladding [2], [9];
- Alloying [10], [11];
- Hardening [11];
- Electron beam rapid prototyping [12], [13] etc.

The unifying factor that connects all these methods is that they are characteristic only for blanks obtained by classical methods such as casting and plastic deformation, or only for obtaining parts through so-called additive technologies and, in particular, 3D printing with metal powder.

Considering the advantages and disadvantages of both technologies, the question arises: is it possible and what will be obtained by electron beam welding of two dissimilar workpieces, one obtained using traditional technologies, and the other using additive technologies and 3D printing of metal powder.

Scarce information about such welding was found on the Electron Beam Processes Ltd website [14] for an example of an electron beam welded Titanium Additive Manufacturing body with Turned ring from stock bar, which does not provide detailed information about the implementation of the process.

The object of the study is obtaining a monolithic defect-free joint using electron beam welding between two dissimilar workpieces with similar properties, which are products of two fundamentally different technologies.

II. MATERIALS AND METHODS

A. Materials

The selection of materials for the blanks used (metal powder for 3D printer and metal blank) was made based on the following criteria:

- Specificity of the existing equipment.
- The selected materials must be non-magnetic.
- The materials must have a certain chemical composition, physical and thermal properties.
- Application of the parts obtained by electron beam welding, etc.

316L stainless steel is an austenitic corrosion-resistant steel with excellent weldability, regardless of the welding method used. It is used in food preparation equipment, especially in chloride environments, pharmaceuticals, marine applications, medical implants, including pins, screws and orthopedic implants such as total hip and knee prostheses, etc. [15], [16]. It has a chemical composition listed in Table 1.

TABLE 1 COMPOSITION RANGES FOR 316L STAINLESS STEELS

Chemical Composition							
Grade	C	Mn	Si	Cr	Mo	Ni	N
Min	-	-	-	16.0	2.00	10.0	-
Max	0.03	2.0	0.75	18.0	3.00	14.0	0.10

On the other hand, LaserForm Maraging Steel (B) is designed for use on the ProX DMP 200 metal printer, producing industrial parts and tool inserts with a combination of high strength and excellent hardness [17].

It is easily heat treatable by an age hardening process, which results in excellent hardness and strength. In terms of subsequent processing, the material shows good weldability and machinability and is corrosion resistant. It is used for: tools and molds for injection molding, die casting and extrusion; high-performance industrial parts, e.g. the manufacturing and automation; high-wear components and aerospace. Its chemical composition and properties are listed in Table 2.

TABLE 2 COMPOSITION RANGES FOR FOR LASERFORMMARAGING STEEL (B)

Chemical Composition								
Grade	Fe	Ni	Co	Mo	Ti	Si	Mn	C
Min	Bal.	17.0	9.0	4.0	0.9	≥1.0	≥1.0	≥0.03
Max		19.0	11.0	6.0	1.1			

The two selected materials have properties that meet the requirements set out above.

To carry out the experiments are used rectangular blanks with geometric dimensions as follows: width $b=10\text{mm}$, $s=10\text{mm}$, $l=30\text{mm}$, and a ProX DMP 200 3D printer was used to make the blanks from LaserForm Maraging Steel (B).

B. Electron beam welding machine

EBW process was carried out with an Evobeam Cube 400 welding unit manufactured by Evobeam (Fig. 1). In Table 3 was presented Specification of Electron Beam Welding Machine [18],[19],[20].

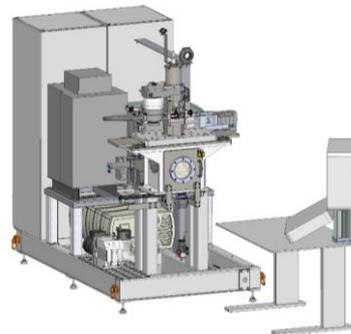


Fig. 1. Evobeam Cube 400 welding unit manufactured by Evobeam.

TABLE 2 SPECIFICATION OF ELECTRON BEAM WELDING MACHINE

Elements	Description
Vacuum chamber	300 x 300 x 300 mm
Chamber pumping system	High Vacuum Turbo-Molecular-pumpset system
Electron Beam gun system	High Vacuum Turbo-Molecular-pumpset system
Manipulation system	3 mechanical CNC axes: X, Y and C all interpolated; 4 virtual CNC-Axes: IX, IY, IB und IL
Gun vacuum	5.10^{-4} mbar
Accelerating Voltage (U_a)	60 kV
Beam Current (I_f)	0-100 mA
Welding speed (V)	0-2500 mm/min

Based on previous studies related to the EBW process of various materials, the following technological parameters were selected: Accelerating voltage $U=60\text{kV}$, Focusing current $I_f=1480\text{mA}$, Welding speed $V=96\text{mm/min}$, Beam current $I_b=20\text{mA}$.

C. Microstructural analysis

To determine the quality of the weld obtained after EBW, a microstructural analysis was performed. A microsection was made from sample using a standard procedure: The test specimen was sanded manually using sandpapers of different sizes from 500 to 2500 mm. It was then polished with DiaMax diamond paste and developed with 4-10% aqueous HF solution for an optimum time of 45 s.

Vickers microhardness was measured along the cross-section of the weld seam in two parallel lines. The first was located at a distance of 1mm from the surface of the weld, and the second (bottom of weld zone) - at a distance of 3mm from the first. A semi-automatic microhardness tester, "ZWICK/ Indentec-ZHV μ -S" (ZwickRoell, Ulm, Germany) with a loading force of 0.5 N was used.

A scanning electron microscope (SEM) was used to determine the distribution of the elements constituting the structure of the obtained compound. An elemental analysis of the composition of the studied sample was performed using energy-dispersive X-ray spectroscopy (EDX).

III. RESULTS AND DISCUSSION

An electron microscope Neophot 32 was used to determine the presence of defects. Fig. 2 shows that there are no defects, there are clearly defined areas characteristic of electron beam welding Fusion Zone (FZ) and Heat Affected Zone (HAZ), and the structure formed in the seam is typical for this type of welding.

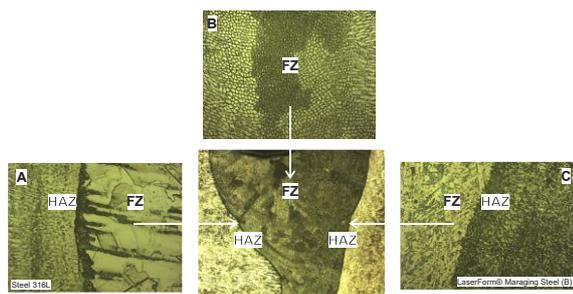


Fig. 2. Weld seam of both materials at x 50 magnification and transition zones at x 500 magnification between: A) 316L steel and weld seam; B) within the weld seam itself and C) weld seam and LaserForm Maraging Steel (B).

To obtain more information about the chemical composition of the studied sample, a straight-line EDX analysis was performed (Fig. 3).

The purpose of performing this analysis is to establish the distribution and concentration of chemical elements (mostly Cr, Ti, Co and Ni) with a predominant percentage content in the main zones HAZ, FZ and in the individual materials of the blanks.

The analysis shows redistribution of chromium. Before welding, it predominates in 316L steel and in LaserForm Maraging Steel (B) it is absent. After welding, its content, albeit a little, is also found in LaserForm Maraging Steel (B).

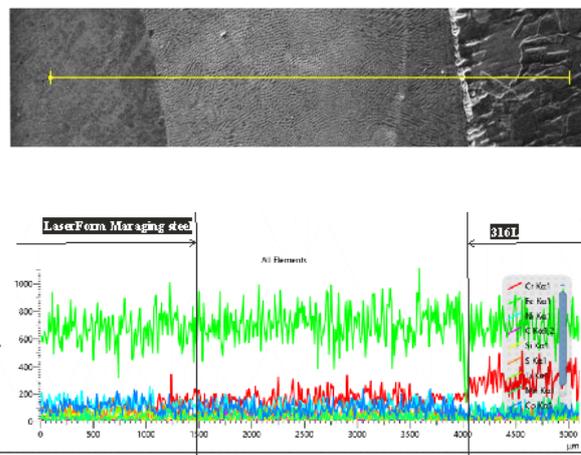


Fig. 3. Line EDX analysis in HAZ and FZ of weld.

Fig. 4, Fig. 5 and Fig. 6 present EDX analysis at points located in the HAZ and FZ.

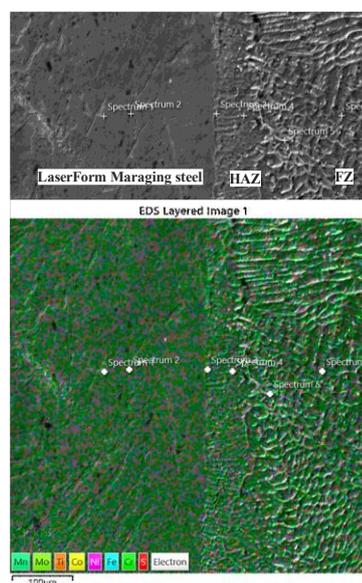


Fig. 4. EDX analysis in HAZ and FZ of weld LaserForm Maraging Steel (B).

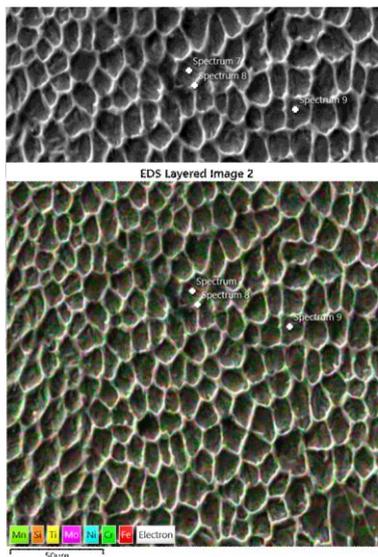


Fig. 5. EDX analysis in FZ of weld

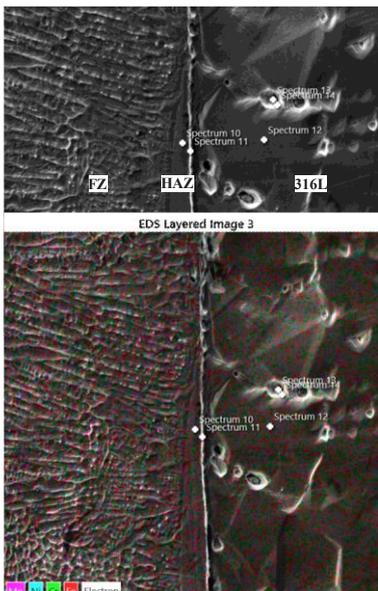


Fig. 6. EDX analysis in HAZ and FZ of weld of AISI 316L Stainless steel.

The microhardness of the used blanks before and after EBW was also measured. The average measured value of microhardness before welding for AISI 316L Stainless steel it is 432 HV_{0,05}, and for LaserForm Maraging Steel – 445 HV_{0,05}.

Fig. 7 shows the measured microhardness after EBW process.

The figure shows the same nature of the microhardness distribution of the two lines. The FZ and HAZ of the weld are clearly demarcated. There is no higher microhardness value in the weld, as is the case when welding homogeneous or heterogeneous materials. The reason for this is the different technologies used to obtain the blanks.

In the FZ, an average microhardness value of 315.5 HV_{0,05} was measured on the first line and 349.7 HV_{0,05} on the second line.

As expected, higher microhardness values were measured in both HAZ due to the thermal processes that occurred during the process and some elements (e.g. Cr, Ni, Co) from the chemical composition of both materials.

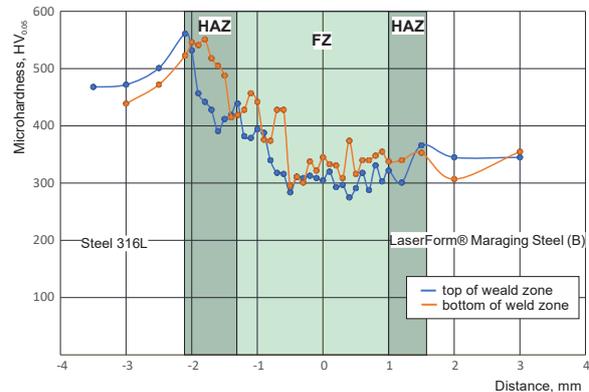


Fig. 7. Vickers microhardness in two parallel lines: the first was located at a distance of 1mm from the surface of the weld, and the second (bottom of weld zone) - at a distance of 3mm from the first.

IV. CONCLUSIONS

In this study, the set goal of obtaining a high-quality, monolithic and defect-free welded joint between blanks obtained by two different technologies (steel 316 L and LaserForm Manganic steel (B)) using electron beam welding was achieved.

The microstructural studies and the measured hardness of a microsection served to prove this. Using an electron microscope, it was found that the resulting weld seam and the areas around it lack defects in the form of pores, voids or cracks. The SEM and EDX analysis established the chemical composition at selected characteristic points of the cross-section of the sample and the homogeneous distribution of the elements with a predominant percentage content, such as Cr, Ti, Co and Ni in both materials.

The measured microhardness (from 315.5 HV_{0.05} near the surface of the section and 349.7 HV_{0.05} at 3mm from it) is also relatively uniform and confirms the presence of a monolithic joint. Compared to that of electron beam welding between homogeneous or dissimilar metals, it has a lower value, but the reason for this is the fact that one of the materials is a product of Additive manufacturing (AM) and 3D printing.

The subject of upcoming research will be determining the optimal mode of electron beam welding as a function of the microstructure and mechanical properties of samples of different materials obtained using different technologies.

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