The electron beam welding of dissimilar materials – case study

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Abstract. The modalities to realize the welding workpieces are multiple. The electron beam welding is one of them. One can weld two different types of materials that give the possibility to reduce the cost of workpiece, if the active part is realised of rich materials welded on components with inferior phisico-mecanical characteristics. The procedure provides great flexibility to the product designs through efficient use of each type of material. So this aspects lead to the necessity to join dissimilar metals. Different tables are given in the specific literature regarding the possible combination. Conflicts may arise by the compromises required for to the optimum heat control of the two dissimilar materials used. But nowadays, more and more frequently are meet the welding of dissimilar metals, thus, the objective of this article is to provide information regarding the particular case of welding between stainless steel and copper without the filler material use.

1. Introduction

The procedures mostly described (traditional procedure or un-conventional methods) for obtaining quality welds mentioned in the literature has been between identical metals or at least welds of metals of similar compositions and properties. There are many applications, however, in which the joints are made from metals of different compositions because in the industrial practice must be resolve the mechanical wear problem or a high-temperature situation, or other conditions in which different properties are required from different parts of the same weldment. This aspects lead to the necessity to join dissimilar metals, because in production, time is money, imposed both of the economical and the functional constraints. A successful weld between dissimilar metals is one that is as strong as the weaker of the two metals being joined, but possessing sufficient tensile strength and ductility so that the joint will not fail in the weld, tells the specialists.

A classification of the most commonly used welding processes for dissimilar materials was realized by Kah [1] and Avery [2]: as fusion weld (shielded metal arc, gas metal arc, gas tungsten arc), low dilution weld (electron beam welding, laser beam and plasma arc) and non fusion weld (friction welding, explosion welding). Avery considered that all fusion welds are dissimilar metal welds because the metals being joined have a wrought structure and the welds have a cast structure. Usually dissimilar metal join are made by fusion, the other two are more often used for high productivity and for special applications [2].

In the electron beam welding case (a low dilution welding method [1, 2]), the welding materials behavior is generally good and can be combined a large numbers of materials but in terms of quality. The main applications of electron beam welding returns to steels, but an important place belongs to dissimilar joints. Tables are given in the specific literature regarding the possible combinations (table 1), so that one can avoid unwanted combination because it forming the intermediary components.

In the electron beam welding process the heat is generated at the impact of high energy electron beam the workpieces. Electrons emitted by a electronic gun are accelerated at a rate that approaches 30% ... 70% of the speed of light and, through their high kinetic energy in contact with the workpiece, releases the heat necessary to achieve the weld. Thus, this process is characterized by high power
density of the order of 108-109 W / cm² that reduces heat loss by conduction and allows controlling the penetration depth of the weld. Also, because of this, the specific areas of the electron beam joint have a temperature gradient much higher than in other welding processes.

Table 1. Workpieces weldment with electron beam (after [23])

|  | Cr | Cu | Fe | Mg | Mn | Mo | Nb |
|---|---|---|---|---|---|---|---|
| Cr | - | 2 | 2 | 5 | 2 | 1 | 5 |
| Cu | 2 | - | 2 | 5 | 1 | 3 | 2 |
| Fe | 2 | 2 | - | 3 | 2 | 2 | 5 |
| Mg | 5 | 5 | 3 | - | 5 | 3 | 4 |
| Mn | 2 | 1 | 2 | 5 | - | 3 | 5 |
| Mo | 1 | 3 | 2 | 3 | 3 | - | 1 |
| Nb | 5 | 2 | 5 | 4 | 5 | 1 | |

1 = Good weldment – wished combinations; 2 = Acceptable weldment – can be obtained complex structures; 3 = Used with precaution – insufficient data in the specific literature; 4 = Used with great precaution – doesn’t exist in the specific literature; 5 = Unwanted combination – are forming intermediary components.

Regarding the welding between stainless steel and copper the researchers were interested to approach this theme lately. Findik and Durgutlu studied this type of joint in explosion welding case [3, 4]. Chen used laser welding in 2015 like a successfully method and obtained a mixed zone of this two materials [5].

Magnabosco [6], Weit et al [7] using electron beam welding obtains a joint with a heterogeneous fusion zone between copper and ASI 304L stainless steel, with a chemical composition characterized by gradual variations in concentrations of iron and copper [8, 9].

The literature [10] mentioned that beam offset can influence the joint Cu-Fe and Shung Guo studied in detailed the diffusion behavior of Fe/Cr, cooling rate and the joint strength. So Cu-Fe alloys are completely miscible in the stable liquid state at high temperatures and do not form brittle intermetallic compounds [3, 9, 10]. Zhang welded stainless steel with copper alloy using copper filler wire [11] and was investigate the effects of process parameters on the tensile strength of the joints, and the optimization of these process parameters.

Even if there are study that investigated dissimilar copper-steel welds, the specific information are not fully established. The present work was focused on the morphological analysis of dissimilar electron beam welded joint between copper and austenitic stainless steel in order to evaluate their potential in industrial application.

2. Materials and experimental conditions

The materials used for the experiment were a copper workpiece and a stainless steel one. It was used an austenitic stainless steel with the following composition: C=0,063%; Mn=1,18%; Si=0,71%; P=0,040%; S=0,017%; Cr=18,307%; Ni=9,93%; Cu=0,328%; Mo= 0,251%; As<0,003%; Al=0,006%; Co=0,162%; Nb=0,055%; Ti=0,017%; V=0,088%; W=0,417%; Pb<0,004%; Sn=0,014%; Mg=0,021%; Zr=0,014%; Bi=0,009%; Ca=0,002%; Ce=0,018%; Ta<0,008%; B=0,002%; Zn=0,025%; La=0,003%; Fe<68,321%.

Generally, these stainless steels have electron beam welding good behavior. Depending on the alloying elements ("chrome equivalent" or "nickel equivalent") may draw conclusions on the peculiarities of welding this material. There are three main categories of stainless steel - ferritic, martensitic and austenitic. Ferritic stainless steels are magnetic and have low carbon content. Its include chromium as the main component, generally in a proportion of 13% ... 17%. Martensitic stainless steels are magnetic, with a typical content of 12% chromium and carbon content of the medium. Non-magnetic steels are austenitic and, in addition to chromium, in the usual concentrations of 18%, containing nickel, which increases the corrosion resistance. In case of stainless steel used for the experimental tests, the percentage of chromium show that it is an austenitic stainless steel (Cr =
18.307% Ni = 9.93%) and a percentage of 68% Fe states that it is a austenitic stainless steel with high carbon grade, which ensures a high corrosion resistance and can be used at high temperatures.

Between two stainless steel materials of the above composition was used a copper material (figure 1). The sandwich structure was preferred other conventional welding because lately the industrial practice uses this type of overlap.

![Figure 1 Micrographs of the sandwich joint- stainless steel and copper](image)

The equipment used in the experiments is a welding equipment electron beam ELA 60/60 (AFE) equipped with a vacuum and working chamber. The few technical characteristics of the equipment are given in the following:- Accelerating voltage - 60 kV; - Welding current, mA - welding regime from 5 to 1000, tracing regime from 2-5; - The current focus, mA 400-1000; - Gun pressure, Pa (mm Hg) - 10.3 \(10^{-3}\) Pa

Working conditions for the research work are presented in table 2, it was realized a joint with a single welding pass but with a current intensity value that ensure the optimal penetration depth.

| Parameters                      | Conditions          |
|---------------------------------|---------------------|
| Acceleration voltage (kV)       | 60                  |
| Current beam (mA)               | 30                  |
| Focal distance (mA)             | 744                 |
| Gun specimen distance (mm)      | 150                 |
| Working chamber vacuum (Pa)     | \(10.7 \times 10^{-2}\) Pa |
| Electron beam gun vacuum (Pa)   | \(10.7 \times 10^{-3}\) Pa |
| Welding speed (m/min)           | 0.23                |
| Welding pass                    | 1                   |

The EBW (electron beam welding) technology provides strong joints and offers many benefits and has advantages in many applications because of the degree of concentration of the welding energy. But the problems arise between welds of the dissimilar metals related to the transition zone between the metals and the intermetallic compounds formed in this transition zone. So, this transition zone was
analyzed with a scanning electron microscope (SEM). To perform this study a Vega Tescan, scanning electron microscope (model VEGA II LMH) was used.

![SEM micrographs of the analyzed area](image1)

**Figure 2** SEM micrographs of the analyzed area

![Chemical composition of the melting zone](image2)

**Figure 3** Chemical composition of the melting zone

The welding of two dissimilar metals with different melting temperature or thermal conductivity is complicated by the fact that one material will melt prior to the other one, but using a high-power density heating source such as electron beam permits to reach the fusion of both metals.

The results showed welds with poor mixing of materials. The copper have high thermal conductivity than stainless steel which leads to different temperature gradient. Because the melting point is different the initial presumption was that the melting zone and mixing zone will be larger so that the two materials will merge. But the stainless steel it passed like a nail through copper and the mixing zone is very small. Even if the most researchers put in fusion zone this type of welding, the
microstructure studied with scanning electron microscopy emphasized the researcher’s point of view, who study this process like low dilution welding process. The higher density of copper to iron must have as result higher mixing area, but with the effect of gravity, it was performed a riveting.

3. Conclusion
In the electron beam welding case of austenitic steel, the crack phenomena may occur in the hot molten metal, by placing at the grain boundary of phosphorus, silicon and niobium impurities, due to precipitation of chromium carbides. Even if the electron beam welding could be categorized as ideal fusion welding process sometimes the melting zone changes may occur that have the effect on the shape and the structure on the weld like imperfections. In the paper research case metallographic inspection of the joint did not reveal defects such as microcracks or porosity. The two studied materials have large differences in their melting temperature and copper have high thermal conductivity, but with the gravity help the stainless steel acts as a permanent joint like rivet.

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