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Effect of the Welding Filler Material on the Mechanical and Corrosive Behavior of Böhler W350 ISOBLOC Hot Forming Tool Steel

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Abstract

In this study, the effects of different welding filler materials were examined in the case of repair welding of pressure infiltration casting tool made out of Böhler W350 ISOBLOC hot forming tool steel. Three additional welding filler materials were used: Böhler W350 ISOBLOC (same as the raw material), Böhler W300 ISOBLOC and Anviloy® 1150 tungsten alloy. The welds were created with TIG welding method. The used welding filler material has an impact on the mechanical and corrosive properties of the tool. The hardness of the weld was measured to determine its resistance against mechanical stress. The corrosion rate was measured because molten aluminium corrodes workpieces due to its high chemical activity. It was concluded that a single-pass weld corrosion speed is 0.142 ± 0.010 mm/year while a weld containing multiple layers and passes has the corrosion speed of 0.069 ± 0.005 mm/year which is approximately 48% of the corrosion speed of the single-pass weld. Furthermore, the hardness of a weld made with W350 welding filler material significantly drops in the upper layers of the weld, down to 273 HV1 while the hardness of the base material is 495 ± 8 HV1. The results show that the multiple layers and passes welds have better corrosion resistance and less hardness than the single-pass weld.

Keywords

welding, repair welding, Böhler W350, corrosion, hardness

1 Introduction

Hot-forming tool steel is used as a casting tool and mould during the pressure infiltration process [1, 2]. Pressure infiltration is an aluminium die-casting method where the molten metal is pressed into the mould with a pressure capable of reaching 1000 bar. The molten metal fills the cavities in the mould. The casting tool (with the mould inside) is held closed by a high-strength hydraulic system until the metal is not completely solidified. The pressure pushes out air bubbles stuck in the molten metal and provides additional material to compensate the shrinkage during solidification. It is a high-productivity method which provides good surface quality [3–5].

During the process, the casting tool can be damaged. This can be caused by material stuck in the mould, which can cause pressure exceeding the pressure during normal conditions that even the soft molten metal (compared to the hardness of the casting tool) can damage or deform the mould. In addition, the constant high temperature (350–450 °C in the casting tool) and the repeating mechanical stress can lead to the exhaustion of the material of the casting tool. This leads to cracks or even pieces breaking out from the mould.

The Böhler W350 base material of the tool is well resistant to the effects that occur during operation. The mould is constantly lubricated, and corrosion cannot occur due to exposure to oxygen or water. But molten aluminium has a high chemical activity which can lead to the corrosion of the workpiece [6–10]. Due to the size of the tool in the event of a failure, it is almost impossible to replace it in some cases. The product is therefore repaired on-site. The inner surface of the mould has a nitride layer which is grinded out with a high-power angle grinder, and the surface is cleaned from oil and other containments before welding. Welding is a well-proven method for product restoration. Previous studies show that different welding filler materials result in different mechanical properties [11, 12]. The repair has to withstand the mechanical stress just as

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good as the undamaged part of the mould, or it could lead to further cracking.

In this study, the welding filler material's effects on the mechanical and corrosive properties of hot forming tool steel were examined to make sure the best welding quality by the repaired casting tool.

2 Materials and methods

2.1 Materials

The base material was the Böhler W350 ISOBLOC (W350 for short) [13] because it is widely used as the material of the casting tool in the pressure infiltration process [2]. As welding filler material, three different types were used in this study: the same as the base material (W350 ISOBLOC), one similar but not identical hot forming tool steel named Böhler W300 ISOBLOC (W300 for short) [14] and one tungsten alloy called Anviloy® 1150 (Anviloy for short) [15]. The chemical composition of these materials is shown in Table 1.

2.2 Manufacturing

The weldings were carried out with a Syrius Tiger 201 AC/DC welder machine with tungsten inert gas (TIG) welding method, with IWELD AT-20 electrode with ø2 mm diameter [16–19]. The welds were created on a sample with the following dimensions: 120 × 150 × 35 mm. The surface was cleaned with Textar Brake Cleaner cleaning fluid. The welding parameters are shown in Table 2. Welding parameters were based on a previous study made in the department of the Budapest University of Technology and Economics [19–21].

Table 1 Chemical composition of the used welding materials (value in Wt%)

Elements	W350	W300	Anviloy
C	0.38	0.38	–
Si	0.20	0.90	–
Mn	0.55	0.40	–
Cr	5.00	5.20	–
Mo	1.80	1.30	4.00
V	0.55	0.45	–
Fe	Rem.	Rem.	2.00
Ni	–	–	4.00
W	–	–	90.00

Table 2 Welding parameters

Amperage (A)	110
Arc voltage (V)	20
Polarity of welding	DCEN (electrode-negative)
Welding speed (m/min)	0.25
Shielding gas (L/min)	8
Heat input (kJ/mm)	0.09

99.9% argon shielding gas was applied during welding. The welding material was ø2.4 mm rod for the welds created with W300 and W350, and ø3.175 mm (ø1/8") rod for the welds created with Anviloy.

Two different types of welds were created, a single-layer, single-pass weld to determine the basic geometry of a pass, and a multi-layer, multi-pass weld for hardness and corrosion testing. This weld contains 2 layer, 3 passes were placed in the bottom layer and 2 passes were placed in the upper layer the schematic illustration is shown in Fig. 1.

The samples were cut with a Struers Discotom 10 cutting machine. The specimens were embedded in Duracryl Plus resin. The SiC paper was used for grinding, 3 µm crystal liquid was used for polishing, and the surface was etched with 10% Nital etchant.

Pictures were taken from the etched samples with the Olympus PMG 3 optical and Zeiss EVO MA10 scanning electron microscope (SEM), and then the corrosion testing was carried out with a BioLogic SP-150 potentiostat.

3 Results and discussion

3.1 Weld geometry

The base weld geometries were investigated on the single-pass welds to determine how much welding filler material gets melted and added to the base material and how big the area was affected by the welding process. The investigated seam characteristics are shown in Fig. 2, and the exact sizes are shown in Table 3.

The results show that the tungsten-based welding filler material's throat, reinforcement and seam width are more petite. It can be concluded that this is caused by the higher amount of energy needed to melt the tungsten welding rod.

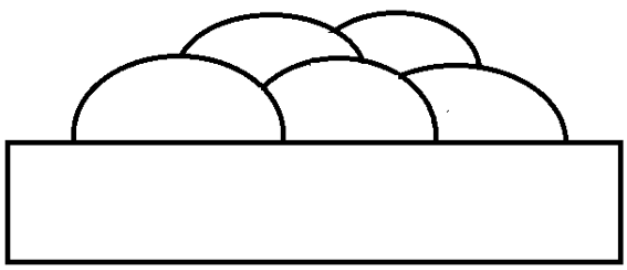

Fig. 1 Schematic illustration of cross section of the multi-layer weld

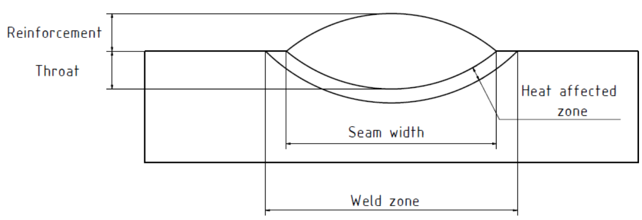

Fig. 2 Illustration of the investigated weld geometries

Table 3 The size of the weld geometries (values in mm)

Seam characteristic	Anviloy	W300 ISOBLOC	W350 ISOBLOC
Throat	1	1.7	1.7
Seam width	6.9	10	7.9
Heat affected zone	1.8	2	1.6
Weld zone	9.6	12.1	10.9
Reinforcement	0.3	0.9	0.7

The difference between the W300 and W350 material was attributed to the free-hand welding process.

3.2 Microstructural and chemical composition investigation

During the microstructural investigation, it was determined that multi-layer samples have finer grain size than the single-pass samples, which can be seen in Fig. 3. This is unusual because most of the time, multiple passes result in slower cooling speed which leads to bigger grain size. Other than that multiple layers result in multiple heat treatment to the affected area which lead to grain coarsening and bigger grain size [22].

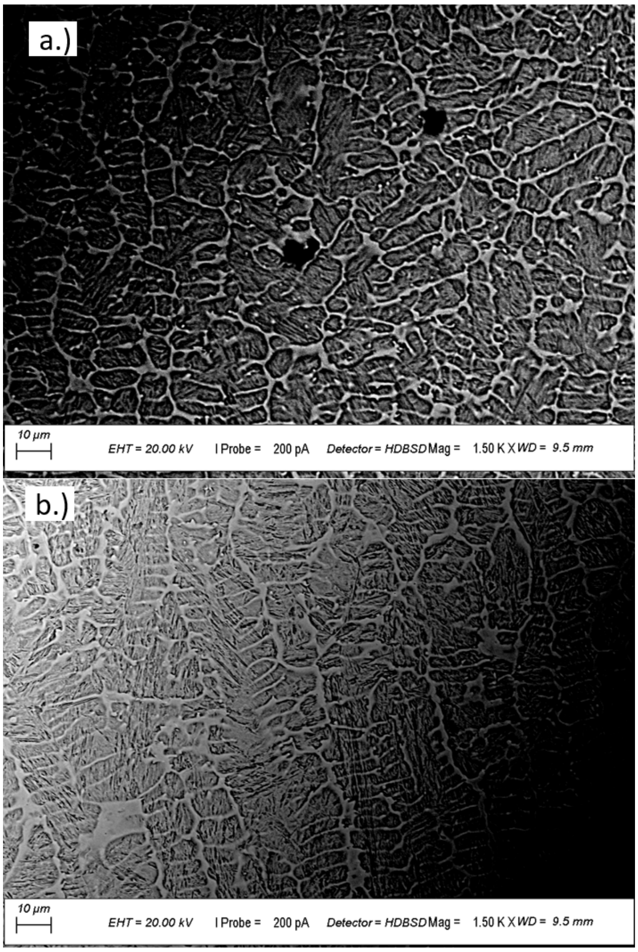

Fig. 3 Grains in the seam of the W300 single-layer (a) and multi-layer (b) samples

In the seam of the Anviloy multi-layer sample, tungsten segregations were discovered, as shown in Fig. 4. The following EDAX Elect Plus type Energy-dispersive X-ray spectroscopy (EDS) showed that, on average, the seam contains little tungsten, while specific points show tungsten content over 80%, as shown in Fig. 5.

The spot with the highest tungsten content was investigated further with high-magnification pictures. As it is shown in Fig. 6, it is not a piece of welding filler material which dropped into the molten metal during the welding process. But a tungsten-rich region where the tungsten segregates on grain boundaries.

In the case of W300 and W350 welding filler material, the samples were nearly indistinguishable from each other based on the EDS measurements because the margin of error of the EDS is greater than the difference between the two welding filler materials in the case of most alloys. The margin error of the EDS measurements is 35.56 ± 1.43%, while the difference in the case of most elements is 19.27 ± 11.19%. The only expectation is silicon, where the difference is 77.78% and the highest margin of error is 65.9%.

3.3 Hardness testing

The ISO standard micro-hardness testing was carried out with 1 kg load [23]. As a base value, several measurements were made to determine the hardness of the base material. This value is 495 ± 8 HV1. While the surface of the mould went under a nitriding process at the end of manufacturing, this cannot be repeated in case of repair. The nitride layer is

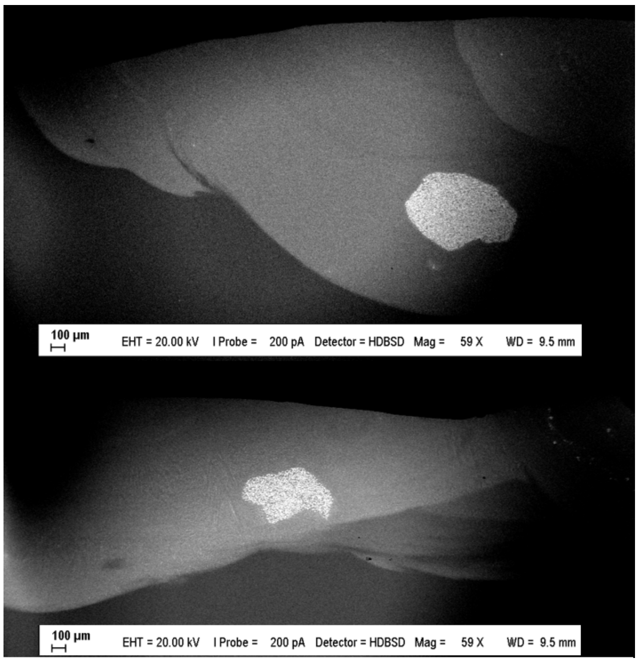

Fig. 4 Two different tungsten segregation in the seam of Anviloy multi-layer sample (tungsten segregation is white)

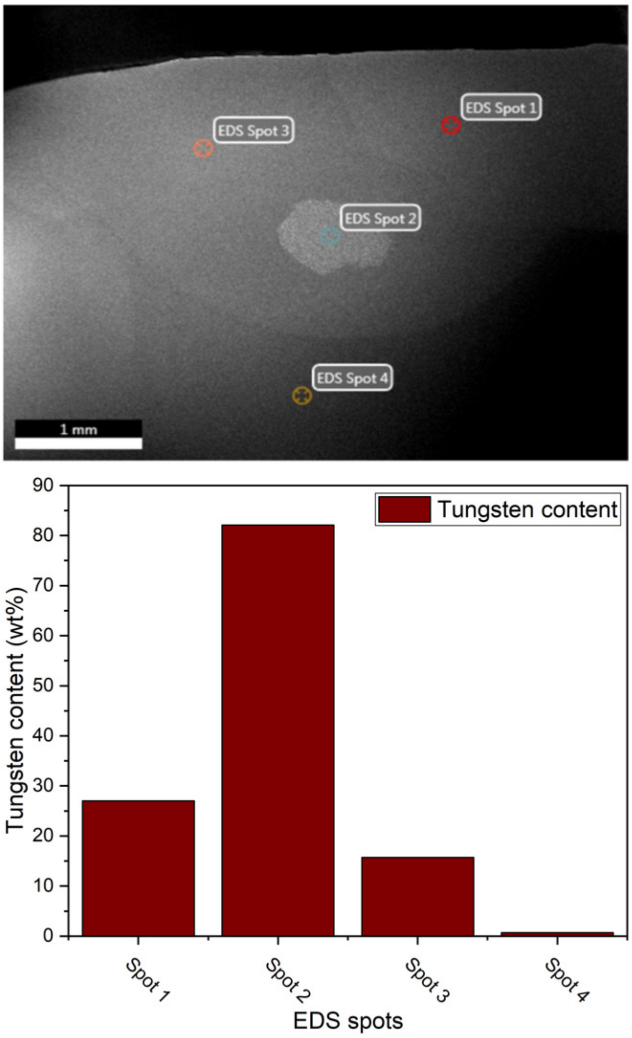

Fig. 5 Eds spots and the measured tungsten content in weight percentage in Anviloy multi-layer sample

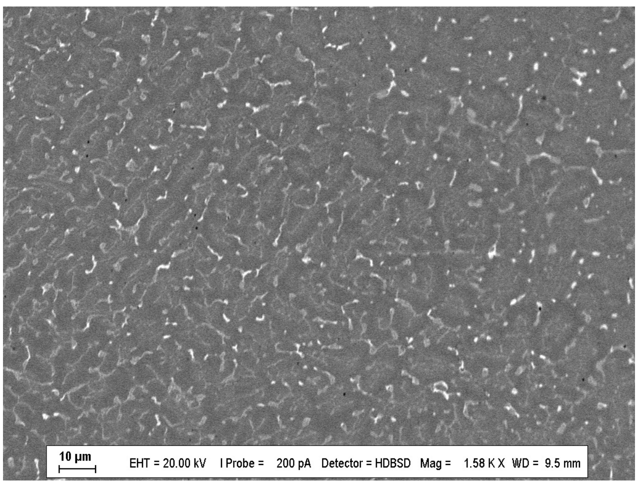

Fig. 6 High magnification image of the tungsten-rich area

grinded out before repair, as previously mentioned, as part of the cleaning of the surface. Because of this, if the top layer of the weld reaches the hardness of the base material, it counts as an accepted weld in this study. The results of the hardness testing are shown in Fig. 7.

The results show that the Anviloy and W300 ISOBLOC produce acceptable hardness, but the W350 ISOBLOC does not reach the base hardness on the surface level. But even that sample has a proper hardness in deeper layers and in the heat-affected zone. It means that by building up the reinforcement with additional layers and then machining down, it can be used as an adequate welding filler material. The specimens were sanded and polished again for corrosion testing after the hardness testing.

3.4 Corrosion testing

The experimental setup is shown in Fig. 8. The specimens were masked with electric tape, and only a small area (0.091 ± 0.023 cm^2) was uncovered on every sample over the seam. The Tafel curves are shown in Fig. 9. The result of the evaluation of these plots is shown in Table 4.

The results show that the single-layer single-run welds corrode faster than the multi-layer multi-pass welds. This is owing to the finer grain size of the multi-layer samples. The cause of this is the previously represented finer grain size of the multi-layer samples.

4 Conclusion

In this study, the effect of three different welding filler materials was investigated in the case of repair welding of

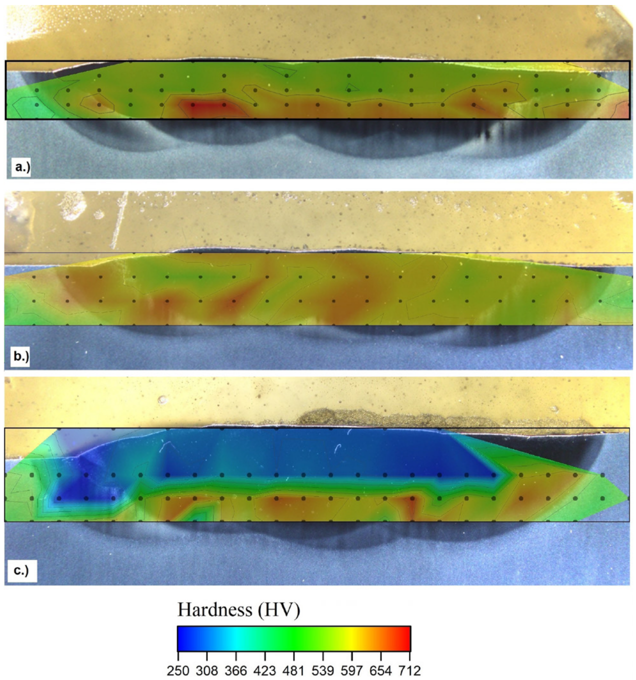

Fig. 7 Representation of the results of the hardness testing on the Anviloy (a), W300 (b) and W350 (c) sample

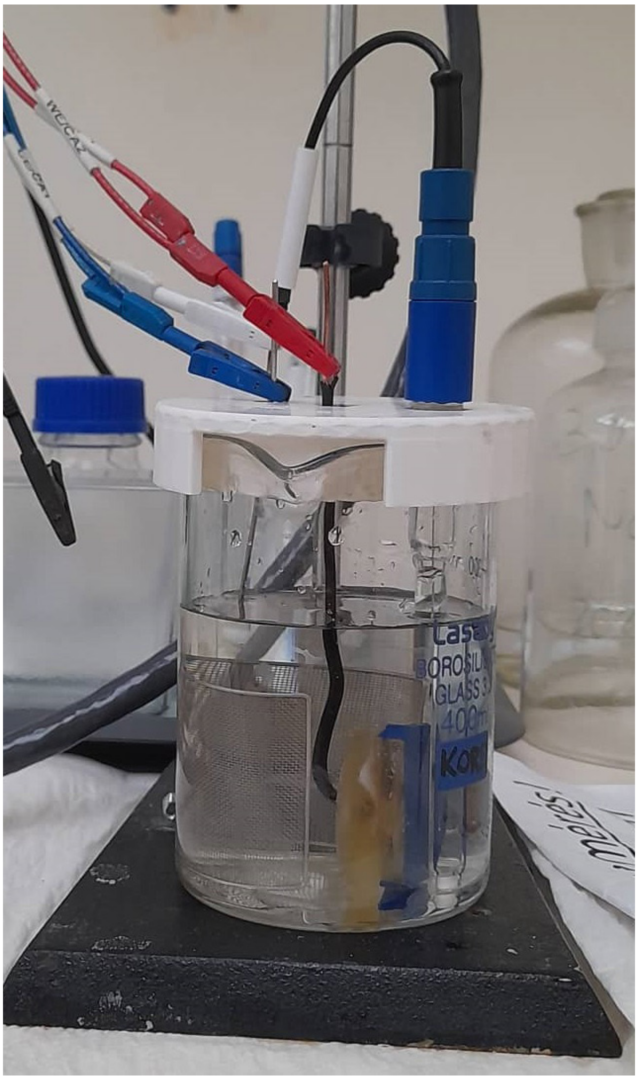

Fig. 8 The experimental setup for corrosion testing

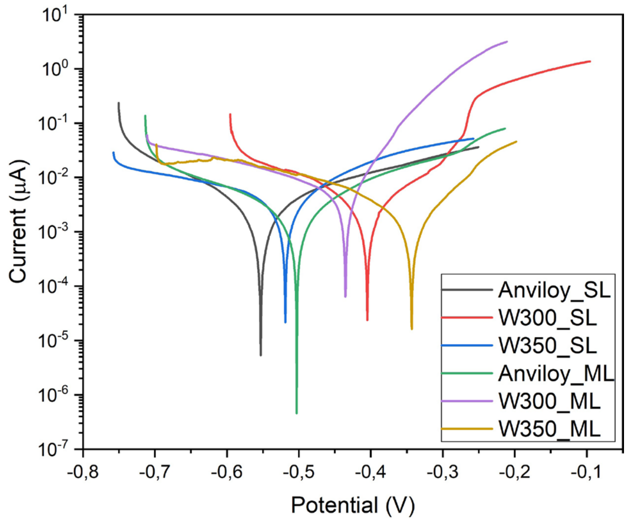

Fig. 9 The Tafel plots of the different samples (SL marks the single-layer, single-pass samples; ML marks the multi-layer, multi-pass samples)

Böhler W350 ISOBLOC hot forming tool steel. During the investigation, the following conclusions were made:

- Both the welding filler material and the welding process impact the properties of the base material in different ways. As the results show, the material affects the mechanical properties while the process impacts the corrosive properties.
- In the case of the use of W350 welding filler material, the hardness of the upper layers declines down to 273 HV1 while the hardness of the base material is 495 ± 8 HV1. This could have a positive effect on the heat cracking resistance, but the further positive and negative effects require further investigation.
- Unlike early expectations, the grain sizes of the multi-layer welds are smaller than the grain sizes of the single-run welds, which leads to slower corrosion speed in the case of multi-layer welds. This leads to the conclusion that even in small cracks, it is advantageous to use multiple passes and machine the reinforcement down compared to a single-pass weld.
- The tungsten from the tungsten-based welding filler material can segregate in the seam in the case of free-hand welding. This leads to non-homogenous mechanical properties, which can have adverse effects on the performance of the workpiece. But these effects require further investigation.
- The corrosion rate of the multi-layer, multi-pass samples was approximately 48% of the corrosion rate of the single-layer single-pass samples. This could be due to the heat treatment of these two layers during welding, which leads to less ferrite and makes better corrosion resistance.

Table 4 Results of the corrosion testing

Sample	Corrosion rate (mm / year)	E_{corr} (mV)	I_{corr} (μA)	β_a (mV)	β_c (mV)
Anviloy SL	0.164	−554.708	2.588	231.000	156.600
W300 SL	0.132	−405.431	2.072	106.200	111.100
W350 SL	0.130	−518.539	1.352	66.000	94.400
Anviloy ML	0.062	−502.191	1.673	140.400	171.200
W300 ML	0.080	−435.609	2.352	44.400	106.100
W350 ML	0.065	−343.740	2.527	111.600	242.100

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