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Microstructural aspects of repairing unalloyed cast steel with around 0.3% carbon content using welding technology

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Abstract

In this work, the results of tests on castings made from unalloyed cast steel, which was repaired using surface padding, have been presented. The purpose of the work was to present the impact of the application of welding technology on the microstructure of cast steels and the dangers related to it. The appearance of a very adverse microstructure was found in the area where the padding occurred. In the light of the presented research, it seems that it is necessary to apply normalizing annealing after the padding of a cast, which will result in a more uniform and fine microstructure of the material being obtained. As a consequence, this will prevent possible operating damage from occurring in the finished products.

Introduction

Despite continuous improvement in casting technologies, it is still not possible to produce a casting that is completely free of defects. Castings still have defects that prevent their direct application, and the complexity of the forming defects frequently makes this difficult and means that advanced methods to diagnose this are necessary (Zawadzka & Łybacki, 2008).

In compliance with the PN-85/H-83105 standard, the concept of defects is associated with each change in the shape and surface, as well as breaks in continuity and irregularities of the internal structure of a cast (PN-85/H-83105, 1985; Zawadzka & Łybacki, 2008). The above standard has been replaced without its equivalent being indicated, but the classification of defects that is presented in it remains relevant. One of the more important methods that are used to repair casting defects is welding. The technology of casting repair allows for the reconstruction of external cavities that were created at the casting stage, belonging primarily to the first and third groups of the above standard, i.e. defects in the shape and breaks in casting continuity. In particular, they belong to cracks, casting misruns, exterior porosity or blowholes. It is extremely important that the method guarantees the proper and reliable operation of the repaired casting. Its specifics fundamentally influence the final microstructure and properties of the cast product (Wojciechowski & Kowalski, 2013; Piwowarczyk et al., 2014; Bęczkowski & Gucwa, 2015; Bęczkowski, 2017; Mičian et al., 2018). Padding is used for this purpose; this involves melting additive material with the base material. Surfacing areas are characterized by the heterogeneity caused by the crystallization processes.

The weldability of the base material determines the success of surfacing unalloyed steel. The basic parameter that defines weldability is the CEV carbon equivalent value, which allows the ability of materials to form brittle, hardened structures (martensite and bainite) to be predicted. It is obvious that unalloyed steels and cast steel with a carbon content not exceeding 0.2% are considered to be materials with high weldability. The weldability of steel with a slightly higher carbon content is not obvious in the literature. Steels containing up to 0.30% carbon are considered steels with satisfactory weldability. Some of the literature indicates that no preheating is required for this value of carbon content (Mičian et al., 2018). Other papers point to their tendency to harden in SWC, which may require heating before welding (Grigorenko & Kostin, 2013; Kozioł & Organek, 2015; Bęczkowski, 2017). The risk of this grows with a higher manganese content, thicker sections and stiffening of the structure (Grigorenko & Kostin, 2013; Kozioł & Organek, 2015; Bęczkowski, 2017). One of the basic requirements for weldability is the use of an additive material with a chemical composition that is equivalent to that of the parent material (Mičian et al., 2018).

The purpose of the paper is to present the influence of the applied casting repair and regeneration method, using surface padding, on the microstructure of cast steels with a carbon content of 0.28% and the dangers related to it. A significant proportion of casting defects are caused by the occurrence of microstructural defects, which become locations for fatigue crack initiation. This may lead to their propagation, and finally to the construction being damaged, especially in conditions of variable loads. For this reason the knowledge of such an impact and methods to eliminate them are extremely important, as this may allow damage to these products that are subjected to these technologies to be prevented.

Materials and methods

The material used for the research was the steel castings that were delivered for tests due to the difficulty in machining them. The tests were performed in the research laboratory of the Machinefish Materials & Technologies Company and the sample collected from the casting was subjected to regeneration with the pad welding method. The macroscopic tests were performed with the use of a Leica M205 C stereoscopic microscope. The microscopic tests were performed with the use of a Leica DM 6000 and a Phenom World ProX microscope. Hardness measurements were performed using the Vickers method using a Zwick Roell ZHU 8187,5LKV testing machine.

The chemical composition of the casting that was tested using a Leco Glow-Discharge Optical Emission Spectrometer GDS-500A has been summarized in Table 1. Due to the fact that the grades of the unalloyed cast steels are classified on the basis of the mechanical properties, the grade of the tested cast steel could not be unequivocally determined.

Table 1. The chemical composition of the tested cast alloy

Element	C	Mn	P	S	Si	Cr	Al	Cu	Ni
Content [w/w %].	0.28	0.49	0.018	0.019	0.57	0.12	0.12	0.04	0.03

Results and discussion

As a result of the macroscopic observations of the casting surfaces, the appearance of numerous casting defects and surface discontinuities in the form of open blowholes was found, as well as partial melts created as a result of the padding repair to the casting (Figure 1).

In order to perform microstructural observations of the casting, two samples were collected from the locations subjected to padding which were selected on the basis of the macroscopic observations.

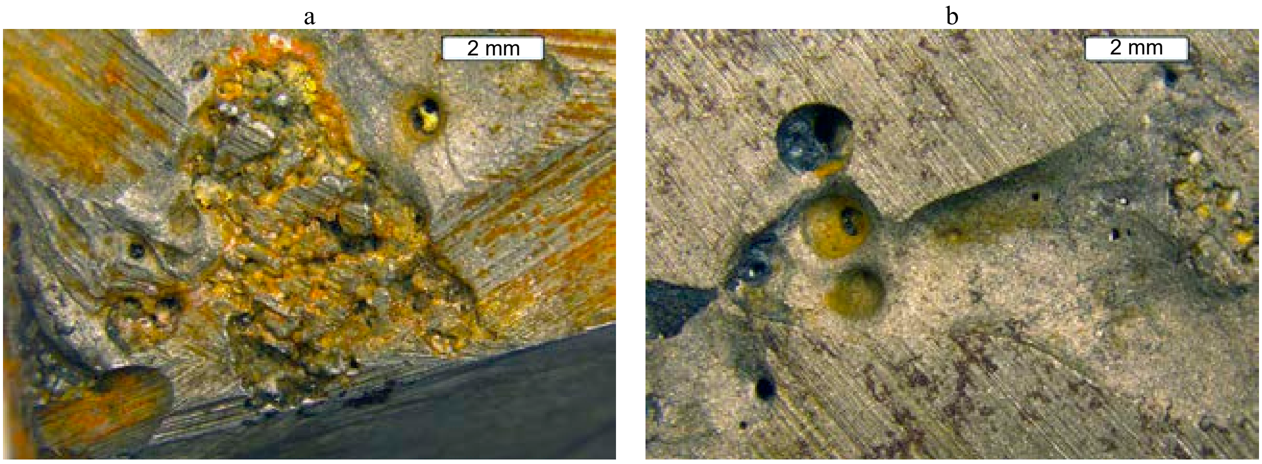

Figure 1. Stereoscopic image of the surface defects in the tested casting. Blowholes open to the surface and morphology indicating padding of the cast

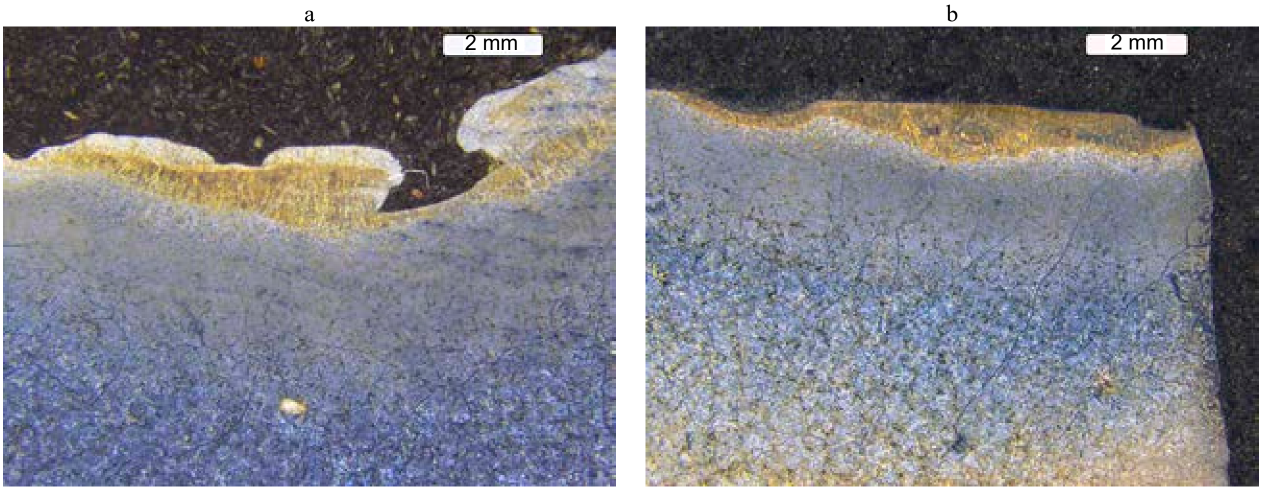

Figure 2. Stereoscopic images of the metallographic macrosections performed in location 1 (a) and 2 (b). Visible padding at surface of the casting: Etched state

The macrosection observations confirmed the occurrence of padding in the tested locations; their macrostructure is shown in Figure 2.

The microscopic observations of the core material of the tested casting in the non-etched state have shown the occurrence of a large number of fine globular non-metallic inclusions. In addition, numerous near-surface casting defects, both open and closed, were revealed (Figure 3). In the core material, the appearance of ferritic – pearlitic microstructure of Widmanstätten morphology was found (Figure 4). This microstructure of the tested component is indicative of its coarse-grained structure, as well as that it was not subjected to the normalizing operation.

In the area of the padding, the appearance of a very non-homogeneous microstructure with Widmanstätten features was found. In the near-surface zone, a coarse-acicular martensite characteristic, for structures created as a result of the martensitic transformation from coarse-grained austenite, was observed. Locally, areas of feathery upper bainite areas were also observed which showed very high brittleness because of the easy nucleation of cracks in the large carbides that precipitated between the ferrite slats. Such a morphologically adverse microstructure led to the creation of numerous cracks during padding (Figures 5–9). The creation of the cracks was also favored by the appearance of continuous sulphide separations over the grain boundaries of the former austenite that was observed in the microscopic tests accomplished with the use of scanning electron microscopy methods. This type of precipitation is created in the case of the appearance of iron sulphides with a low melting point and they contributed to the creation of hot cracks in the cast steel (Figures 10 and 11).

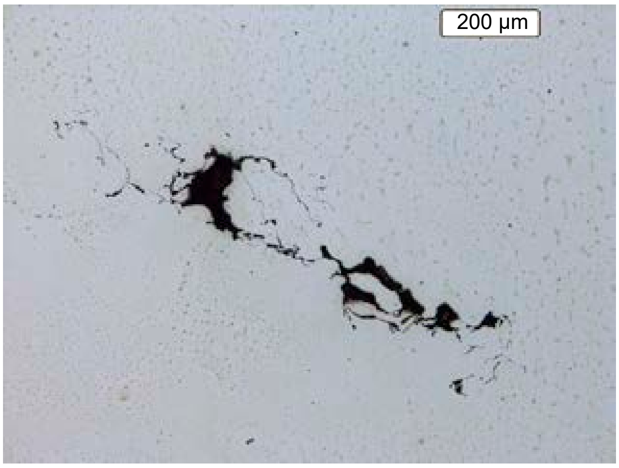

Figure 3. Microstructure of the material in the non-etched state. There are visible surface defects and globular non-metallic inclusions in the casting material: Taken with light microscopy

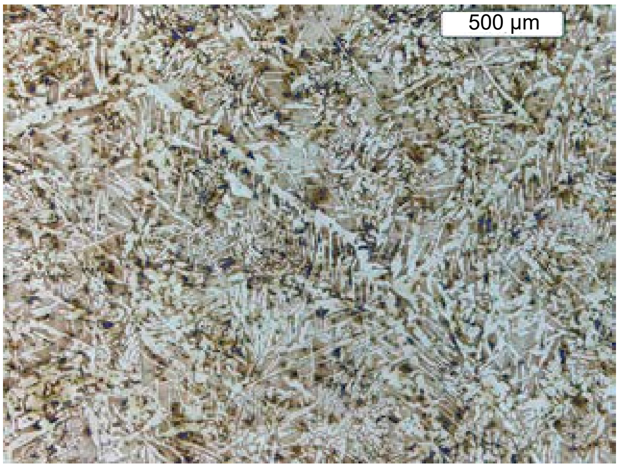

Figure 4. Microstructure of the tested casting core. The ferritic – pearlitic microstructure of Widmanstätten morphology is visible: Etched state

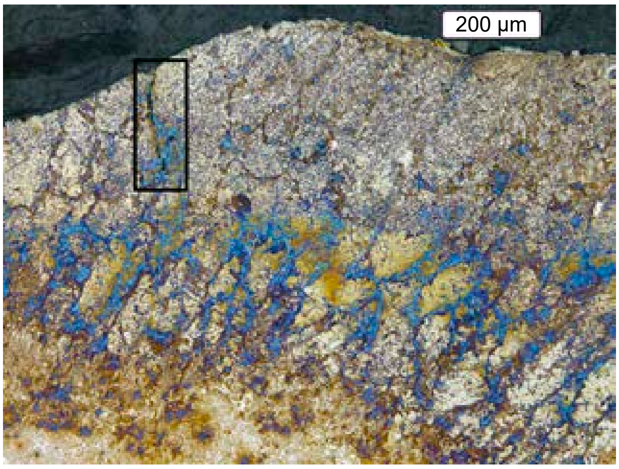

Figure 5. The near-surface microstructure of the tested casting in location 1. The visible disparity in the microstructure of the material and a crack propagating over the grain boundaries are marked with a frame; Etched state

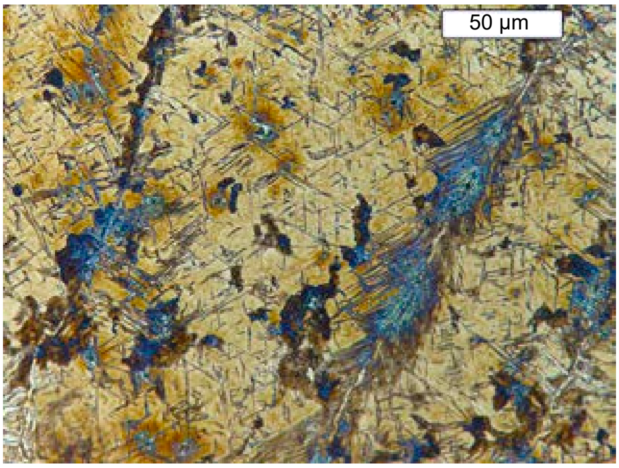

Figure 6. The microstructure of the padding in location 1: Magnified fragment of the area from Figure 5. There is visible martensite with a lot of residual austenite and locally appearing feathery bainite: Etched state

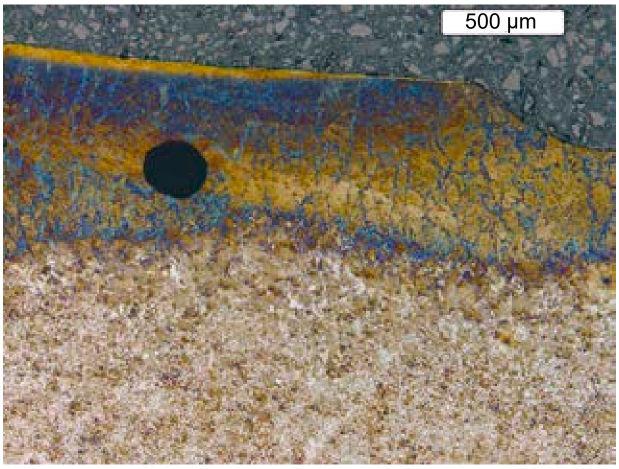

Figure 7. The near-surface microstructure of the tested casting in location 2. There are visible mircropores and disparity of the microstructure of the material: Etched state

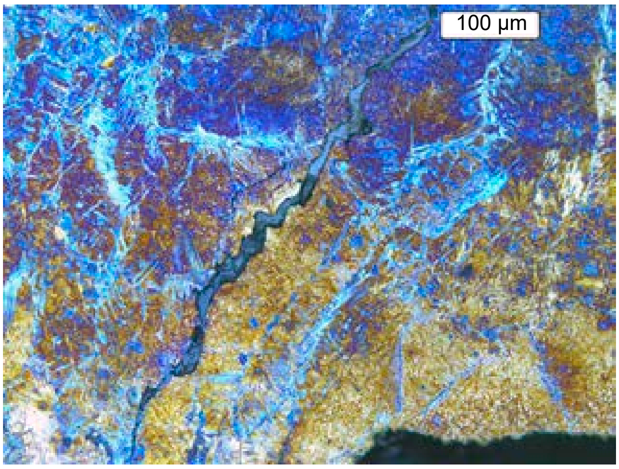

Figure 8. The microstructure of the padding in location 2. There is a visible crack running over the grain boundaries of the former austenite and the microstructure of the coarse-acicular martensite with feathery bainite: Etched state

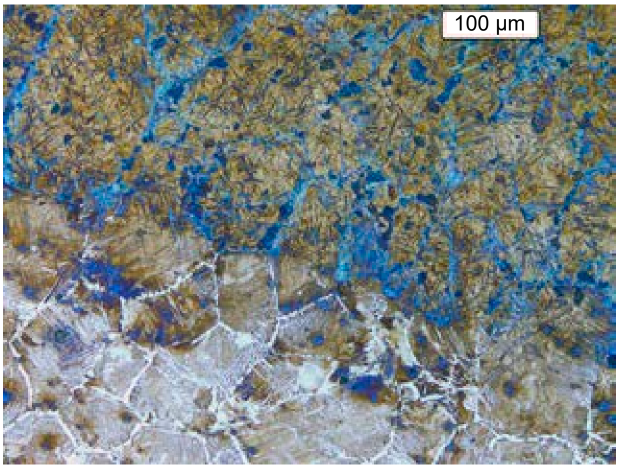

Figure 9. The microstructure of the padding in location 2 showing the transition zone between the padding and the native material. There is visible coarse-acicular martensite with feathery bainite in the area of the padding and the ferritic – pearlitic microstructure in the area of the padding and the microstructure with Widmanstätten structure features in the native material: Etched state

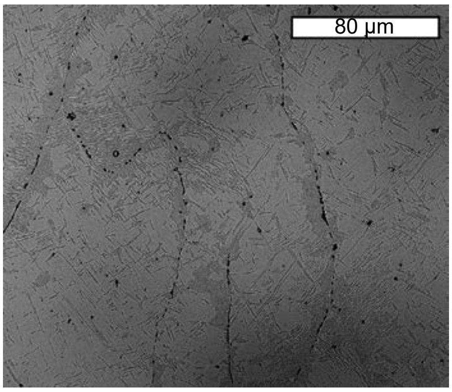

Figure 10. SEM image of the padding in location 1. There is visible precipitation of iron sulfides on the grain boundaries of the former austenite. There are precipitations of manganese sulfides inside the grains: Etched state

a b

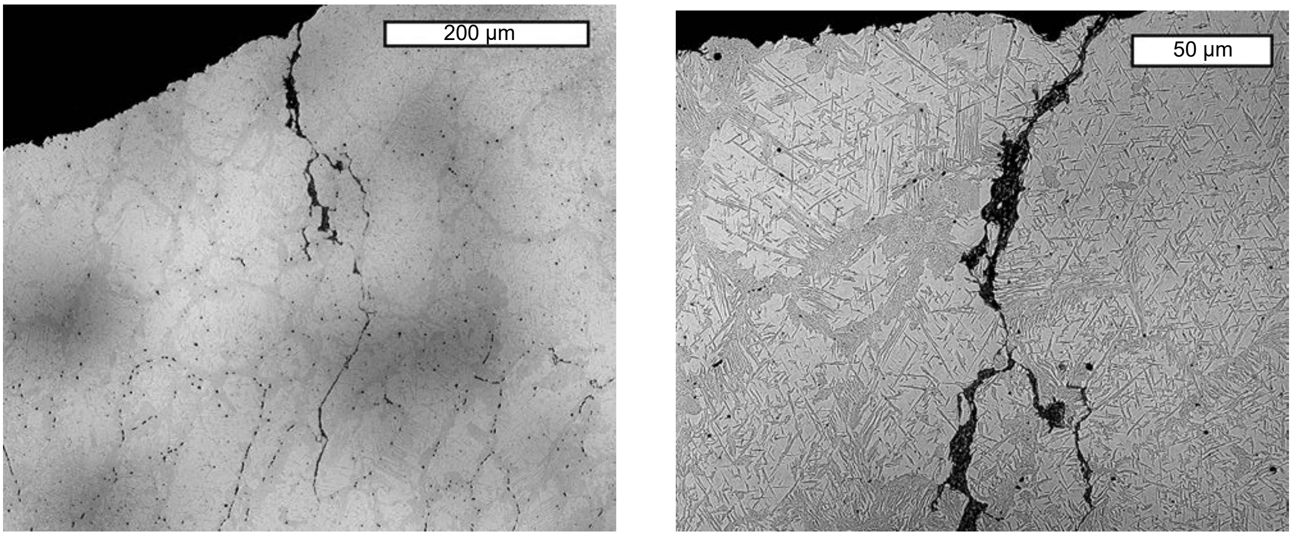

Figure 11. a) SEM microscopic image of the padding in location 1. There are visible non-metallic inclusions and a crack running over the grain boundaries of the former austenite. b) Magnified fragment of the area in image (a)

In the location of the appearance of the padding, a hardness distribution was performed using the Vickers method (HV3), running from the surface towards the core, according to the line shown in Figure 12, on which the obtained hardness results were taken. On the basis of the performed hardness measurements, hardening of the material in the location of the padding was found; this was not especially severe, and confirms the appearance of the padding.

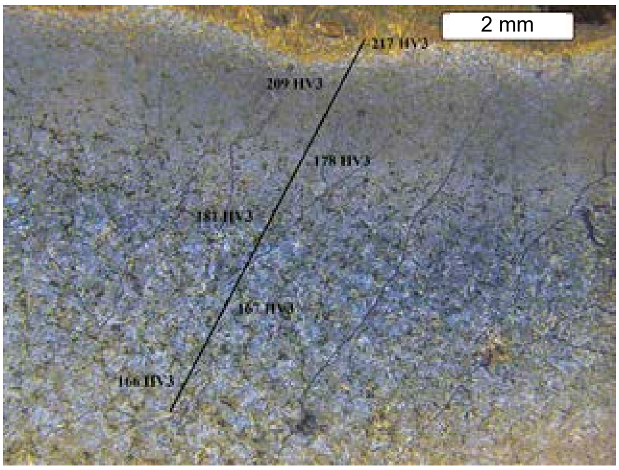

Figure 12. A stereoscopic image of the microstructure in an etched state. The line indicates the course of the performed hardness distribution (HV3) involving the padding, the heat-affected zone and the casting core

Conclusions

Repairing a casting using welding techniques is frequently the only way to correct faults that occur during a steel casting. The aforementioned technology allows the external defects that arise at the casting stage, i.e. defects in the shape and breaks in the continuity of the casting, to be rectified. These include misrun, as well as external blisters, porosity and shrinkage. Padding is associated with covering the surface of the material with welds. It is possible to obtain a padding weld of different thicknesses and chemical compositions on elements of various shapes and surfaces, depending on the welding method used. The basic criteria for the selection of the surfacing method include the quantity and size of the surface defects, the chemical composition of the base material, its weldability, and the required properties, as well as the shape, size and surface condition of the casting.

The specificity of these methods means that the crystallization rate during the process of repairing the casts using the welding methods is much higher than during the original casting. This can lead to frequently unfavorable changes in the microstructure of the material of the repaired casting and it can impact the final quality of a product. This is especially dangerous because the changes mainly concern the areas near the surface, which could contribute to the creation of construction damage. The resulting microstructural changes may become locations of fatigue crack initiation, which is particularly dangerous under conditions of variable loads. For this reason it is necessary to rectify the effects of these repairs.

It seems necessary to respect the rigor of performing the normalizing annealing operation after padding cast steel with around 0.3% content of carbon which will not only enable the correct microstructure of the material to be obtained, but will also remove the stresses created during padding. As a consequence, this will enable the required mechanical properties to be uniformly achieved throughout the whole cross-section of the component.

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