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Spot Welding of Bimetallic White Cast Iron-Nodular Cast Iron

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Abstract. A bimetallic product is the result of the manufacturing process in the form of unification of two materials that have different characteristics so as to obtain a product that has two different properties to be able to meet the specific technical demands as needed. Bimetallic products can be used in for punch and dies for manufacturing tooling. In the manufacture of the dies, hard surfaces and strong inner surfaces are required, thus often applying surface hardening processes to obtain both properties. The process of making and repairing this tool is by applying bimetallic system with spot welding. The basic part is made of nodular cast iron, while the surface is made of white cast iron. By applying electrical current for specific exposure time, a bonding area is built at the interface of both materials. This might consist of fusion and diffusion area. For the thickness of 3mm for each of both materials, electrical current of 40A and exposure time of 15 seconds results a joint interface without any crack and acceptable metallurgical bonding. Testing and analysis of the results have been conducted through microstructure analysis and energy dispersive spectrometry. The results of this study can be applied further on the manufacture of all technical products that require the fusion of two different material properties

INTRODUCTION

Bimetallic goods are widely used as elements in many technical applications which operate in mainly two different conditions. Punch and Dies as forming tools require hard surface until certain depth, while the inner part should performs high impact resistance and toughness. The manufacturing of bimetal products can apply several different methods. In general, the technology of bimetal making consists of two materials which are unified on three systems, i.e. solid-solid, liquid-semi liquid, and liquid-solid. Most of these are based on the metallurgical bonding along the interface between the two constituent materials.

Hessamoddin Moshayedi [1] discovered that the thickness of a nugget is usually less than the thickness of two sheets of metal. The indentation of this nugget is not significant for plate thickness up to 1 mm, but more significant on thick plates / objects. When the change in thickness causes a concentrated voltage at the edges, which may result in initial cracking. Once the welding process in the voltage can still occur / formed in the object.

Daniel J. B. [2] defined a pattern of electrical resistance calculations for symmetric nuggets through the calculation of the total resistance R (t) defined by

$$R(t) = 2.RB(t) + RC(t) + 2.RELM(t) \tag{1}$$

Z. Han [3] found an association between holding cycle with total crack length at resistance spot welding for steels indicating the optimal value of 19 capping cycles as hold time with the shortest crack. The experiments are performed on high tensile steel with 12KA current, load 1600 Lbs. Triyono [4] proved that there are differences in electrical resistance due to differences in the thickness of objects. This condition causes a heat imbalance if spot

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welding is performed on objects of different thickness. As a result, an asymmetrical welding nugget will be formed, in which the nuggets size and depth of thinner side penetration will be smaller than the thicker side of the bag. It is found that the 2-1 mm welding nuggets and 3-1 mm specimens of the asymmetric shape while the symmetrical weld nuggets appear in the joints of the same thickness (1-1 mm joints).

There are differences in electrical resistance due to different objects. Thin objects have lower electrical resistance. Electrical resistance affects the heat generated and the formation of nuggets. Low electrical resistance causes less heat and smaller size zone sizes. In contrast, thick plates produce higher heat and larger fusion zones. This condition causes a heat imbalance if spot welding is performed on objects of different thickness. As a result, an asymmetrical welding nugget will be formed, where the size of the nugget and the penetration depth of the thin sides of the sides will be smaller than the thick sides of the bag. This phenomenon is evidenced in Figure 1. The macrostructures are a) 1-1 mm (b) 2-1 mm (c) 3-1 mm [4]. It is found that the weld nuggets are 2-1 mm and 3-1 mm specimens of asymmetric shape while symmetrical welding nuggets appeared on the joints of the same thickness (1-1 mm joints). The heat imbalance will occur when different thicknesses of the same material, the same thickness of different materials, or a combination of the two join using spot resistance welds [5]

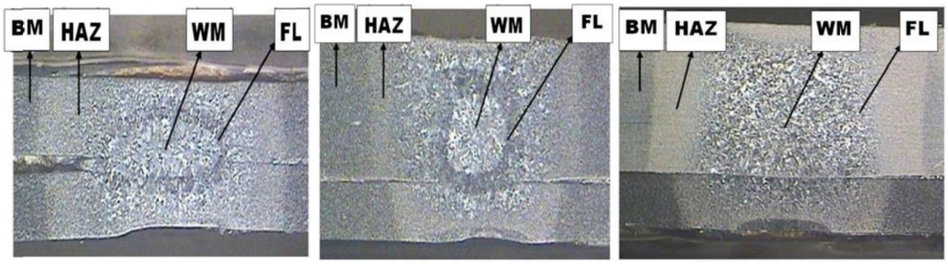


FIGURE 1. Macrostructure (a) 1-1 mm (b) 2-1 mm (c) 3-1 mm [11]

To generate crack-free nuggets and corresponding sizes, appropriate current settings, holding time and compression are required. Han [3] found that the minimum crack length for the steel was obtained at a holding time of 17 cycles.

The basic concept of technology applied in this research is the spot welding of two different types of metallic material to produce a bimetallic material. These two materials were joint metallurgical by mean of fusion and diffusion bonding at the contact area. The proper temperature of preheating and the contact interface temperature should be the concern of this work as well. The preheating temperature should avoid the initiation of crack. This research focuses on the spot welding process without any preheating.

METHODOLOGY

The study includes bimetallic material by means of spot welding which comprises of two parts, hard material and ductile material. Both materials are coupled and pressed together while sufficient electrical current is flown.
Table 1 and 2 describe the chemical composition of the component materials of bimetallic material used in this study.

TABLE 1. Chemical composition of the NiHard1 white cast iron casting

C **(%wt.)**	Si **(%wt.)**	Mn **(%wt.)**	P **(%wt.)**	S **(%wt.)**	Ni **(%wt.)**	Cr **(%wt.)**
3.36	0.38	0.27	0.007	0.009	3.9	2.07

TABLE 2. Chemical composition of the ductile cast iron

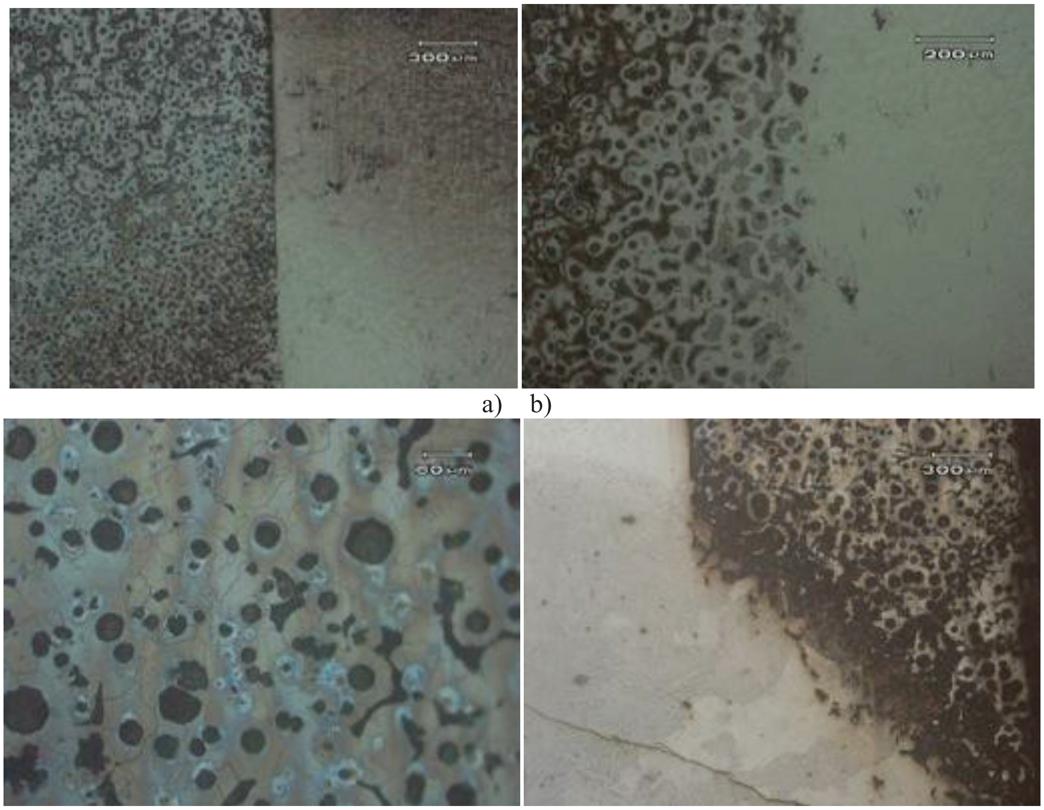
C (%wt.)	**Si (%wt.)**	**Mn (%wt.)**	**P (%wt.)**	**S (%wt.)**
3.74	2.2	0.27	-	0.01

The thickness of the specified object ranges from 5-10 mm for each constituent material. The shape of the object is in a shape of a plate. The determination of barrier value is done by method of direct measurement on object. The energy needed at spot welding is converted from the amount of energy required to melt a number of materials at the interface area. The amount of current and welding time is determined by the amount of energy required. E = 0.24

I²Rt. The experiments are conducted with varying current and time variations to obtain fusion area thickness in the interface zone. The trial results are tested with an optical microscope. This test is carried out through a series of sample preparation and observation processes. EDS testing is conducted to analyze the chemical composition of material at the interface area. The results of microstructure testing are analyzed based on phase change, fusion zone formation, heat affected zone. This analysis also studies the effects of thermal shock on the material microstructure and material resistance. The phase change is examined for both the base material and the interface zone.

RESULTS AND DISCUSSION OF STUDIES

Each of bimetallic products is examined and visually assessed. For further qualitative and quantitative evaluation metallographic analysis is conducted. Testing and microscopically examination is conducted on the whole samples of bimetallic product in order to evaluate the possibility of cracks in the joint area and base material and the microstructure in this area.



a) b)

c) d)

FIGURE 2 . Microstructure of a bimetallic material, a) interface zone consists of diffusion bonded zone and separate zone, b)interface zone with fusion bonding, c) base material d) fusion area and crack

There are mainly three zones present in the joint area of bimetallic product microstructure, as shown in Figure 2. The basic material of inner ring consists of eutectic nodular graphite in the matrix of pearlite and ferrite (c). The second zone, which is the basic material of hard plate has microstructure typical for white cast iron Nihard1 grade. The formation of ledeburitic microstructure of martensite and chromium carbide is clearly described. The third zone is the interface or transition zone which can be diffusion bonded microstructure, fusion bonded microstructure or a combination of these.

Microstructure changes on the base material

The grain size of Nihard 1 microstructure near to the interface shows significant difference to the similar microstructure in the base material. The grain close to the interface is finer and marked by the presence of blade shape carbide.

Microstructures of the ductile cast iron in the base material are not changed significantly. Moreover, the solid state of the ductile iron annihilates the possibilities of new grain formation. Preheating of inner ring does not affect the microstructure of ductile iron base. However, there is microstructure change occurred near to the interface due to the diffusion of elements and partial melting.

The formation of microstructure at the interface

The microstructure of interface area consists of ferrite, carbide, perlite and graphite. Pearlite is formed in colony near to the center of interface area and becomes the dominant phase at the interface due to the change of nickel and silicon content at the interface. Silicon belongs to the element that promotes ferrite. In the interface area, Ni-Hard diffuses partially into the nodular cast iron, which furthermore causes a decrease of silicon content, since NiHard has lower silicon. Ferrite becomes hereby more unstable and get coupled

Atoms of carbon are derived from graphite. Ferrite has subsequently the maximum level of carbon content. At the fusion zone, lower silicon content and high nickel content promotes the formation of pearlite. Carbides which is formed at the interface is similar to that of the base carbide material Ni- Hard, as is indicated with the same chemical composition

Austenite and martensite has not been formed, since nickel as an austenite stabilizing element diffuses only partially into the alloy. To verify the change in elementary content of the microstructure EDS, examination has been conducted.

Microstructure observation using SEM finds two areas, namely the area of fusion and diffusion. In the area of fusion, the distribution of graphite is denser than that in the fusion area, since the two materials are in a liquid state. Although graphite is considered stable, but due to the melting process that occurred, the graphite at the interface could move freely so the graphite tent to less dense. Part of graphite deteriorates and its carbon atom diffuses in the surrounding matrix of Fe and forms another phase, due to the higher diffusion coefficient of graphite on liquid conditions. Microstructure in the fusion area is similar to the micro structure in the Ni-Hard 1. However, there are differences in carbide morphology, in which carbides formed in the area of fusion have a blade-shaped form. Microstructure formed at the interface is dominated by pearlite, but the number of carbides is higher than the two previous specimens. There are two types of carbides at the interface in this specimen, carbide similar to that contained in the base material Ni- Hard 1 and carbides without nickel content in it. The first type of carbides forms in the identical conditions with the formation of eutectic carbides in the base material Ni-Hard 1. The second type is formed by the diffusion of nickel and silicon, which came from the first type carbide. Due to the high temperature, nickel and silicon have the ability to diffuse better. This has been verified by the content of nickel and silicon carbide, in which the first type shows higher the content of both elements.

In the diffusion area, there is practically no longer ferrite present, this happens because of the lower silicon content in the interface. Carbides has a discrete morphology, and compositionally different from the carbide on the base material of Ni-Hard. This is caused by the higher temperature at the interface, in which chromium, nickel, and carbon have the ability to diffuse better. Nickel diffuses into the pearlite phase, while carbon and chromium diffuses into carbide.

Figure 3 shows the area of spot analysis for EDS examination at the interface area and the elemental content. It appears that chemical composition of the interface area shows discrepancy from those of the base material. As described in Figure 4, the silicon content of 1.48% at the interface area promotes the formation of ferrite, whereas the content of Cr and Ni as mentioned before, put themselves each on carbide and pearlite. High nickel content in the alloy and the lower silicon content cause the formation of pearlite colonies without the presence of any ferrite. The percentage of silicon content in the ferrite is higher than the percentage of silicon at the interface as a whole. This is an indication that most of the silicon put itself in the ferrite.

Chemical composition of phase at the interface area.

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Creation:	08/16/2017 2:16:56 PM
Sample Name:	spot welding

Area 1

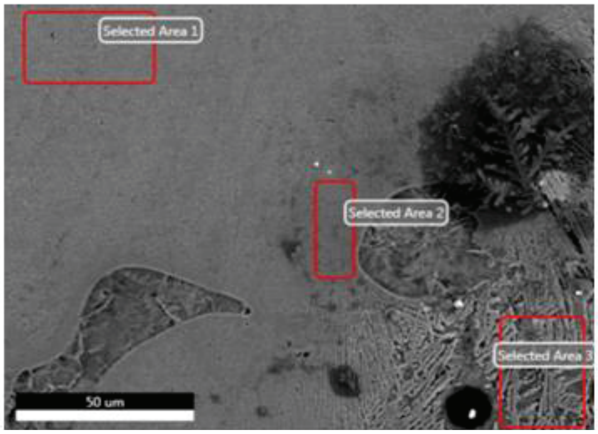
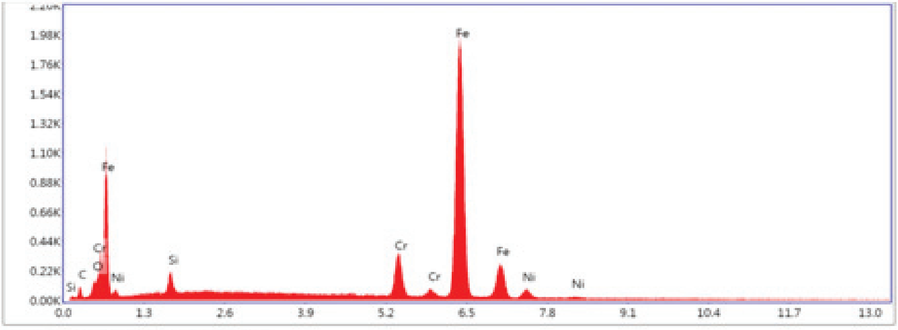


FIGURE 3.area of spot analysis

Selected Area 1

kV: 20 Mag: 750 Takeoff: 36 Live Time(s): 30 Amp Time(µs): 7.68 Resolution:(eV) 124.8

Selected Area 1



Lsec: 30.0 0 Cnts 0.000 keV Det: Octane Pro Det

eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	5.58	20.82	32.21	13.65	0.0155	1.2879	0.8481	0.2152	1.0000
O K	1.02	2.86	24.95	16.09	0.0051	1.2391	0.8727	0.4042	1.0000
SiK	1.48	2.36	69.33	12.45	0.0081	1.1384	0.9305	0.4758	1.0076
CrK	6.95	5.98	273.39	5.67	0.0922	0.9762	0.9996	0.9916	1.3707
FeK	80.99	64.95	1791.25	2.16	0.8025	0.9732	1.0099	0.9886	1.0300
NiK	3.98	3.04	61.42	14.95	0.0367	0.9857	1.0183	0.8995	1.0380

FIGURE 4. Selected Area at the interface for testing of chemical composition with EDS

CONCLUSION

Based on the obtained results, it can be concluded that influential parameters for creation of a metallurgical bonding at the interface of bimetallic spot welding without the presence of crack, i.e. NiHard and ductile cast iron are electrical current, exposure time and the available pressure. On the side of the base material of the bimetallic casting, no change in graphite size and distribution occurred during the welding process. Some changes in elemental content, particularly Cr, Ni and C have taken place and contributed to the changes of microstructure. There is a transition zone formed at the interface as a result of fusion of both materials which influences the chemical content of each prevailing microstructure, mainly in the solid solution matrix. The chemical composition obtained in this zone determines the properties of carbides and matrix structure. Fusion process at the interface results broader transition zone and causes microstructure changes, in which the graphite is dispersed and reduced in its number and size. The hardness of carbide in this area is slightly lower than that in the base material.

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