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COMPOSITE ALLOY WEAR PARTS FOR USE IN THE MINING INDUSTRY

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ABSTRACT

New methods for manufacturing alloy composites have been used to produce a number of wear parts for the mining industry. The use of composites incorporating white cast iron and steel permit brittle and wear resistant materials to be used in applications where moderate impact conditions are encountered. Analysis of the alloy composite interfaces has provided an enhanced understanding of the bonding mechanisms between the white cast iron and the steel and has also permitted further improvements in the manufacturing techniques. Analysis methods used to examine the interfacial features include quantitative x-ray mapping (QXRM) and electron beam backscattered diffraction (EBSD) mapping. Examples of successful field trials include mineral sands dredging and wear parts for heavy earthmoving equipment.

Keywords: alloy, composite, mining, bonding, wear, x-ray mapping

1. BACKGROUND

The use of alloy composites for applications within the mining industry is not new. Established composite products include hard-faced wear plate, vacuum brazed plates and wear bars, various carbide tools inserted into drill bits, and some powder metallurgy products.

Many of the existing alloy composites have limitations with their use based on their methods of manufacture, and in many cases involve expensive capital equipment and high raw material costs. Hard-faced plate is normally produced from multi-head welding machines with a limited deposition thickness depending on the type of welding arc process used. Vacuum brazing of composites requires expensive heat treatment furnaces, usually requiring high vacuums, and also necessitates the machining of the surfaces to be bonded to high tolerances. A summary of some of the various alloy joining processes is shown in Table 1.

In addition to the above restrictions in manufacturing, the composites often have limited design scope, usually requiring flat faces, plates and simple geometric shapes, which in turn require complicated fixing methods with the end user to enable wear protection to be effective.

The performance of composite alloys has now been established in many mining applications, with white iron hard-faced plate and white iron vacuum brazed bars and plates now readily adopted across the industry. The wear performance is provided by the microstructure of the white iron component of the composite, which consists of a microstructure of hard complex chromium carbides supported within a ferrous alloy matrix.

There are many variations in white iron compositions and microstructures that can be achieved through control of the hard-facing raw materials, or cast alloys used for the vacuum brazed products. In general the higher carbide volume fractions have been demonstrated to provide better field performance.

The limitations that exist with current manufacturing methods for alloy composites restrict the application of white iron alloy composites. A more flexible process has been developed that provides the following:

- Flexibility in orientation of the wear product.
- Unlimited thickness.
- Elimination of machining.
- Production of larger composite components.
- Tolerate the differences in thermal expansion of the wear material and the substrate.
- Complexity of shapes.
- Eliminate cracking.

The new vacuum casting process was developed based upon some of the principles for the manufacture of composite alloys using a previously developed vacuum brazing process [1]. In the vacuum brazing process, the mating steel and white iron surfaces are machined to a high tolerance. A thin copper shim approximately 0.1mm thick is placed between the mating surfaces, and the parts to be joined are positioned flat and heat treated within a high vacuum furnace. The temperature is increased until the copper melts and flows across the mating surfaces under capillary action.

During the vacuum brazing process, the presence of the liquid copper at the surface of the steel and the white iron allows the copper to dissolve iron present in these alloys, forming a binary alloy that grows across the interface (refer to Fig 1).

Table 1. Summary of alloy joining processes

Process	Bond	Cost	Shapes	Section Thickness	Wetting	Comments
Welding	Metallurgical	Low	Joints + Pads	< 6mm	Excellent	High distortion
Brazing	Mechanical	Low	Joints	<0.5mm	Good	Low strength
Sintering	Metallurgical	Med/ High	Complex	10-75mm	Good	High pressure
Casting	Mechanical	Low	Complex	10-250mm	Poor	Chilling/ poor bonding
Sol-gel	Metallurgical	Med	Complex	<50μm	Good	Limited thickness
Castbond (CSIRO)	Metallurgical	Med	Plate + Tube	20-75mm	Good	Moulding limited
Explosion	Metallurgical + Mechanical	High	Plate	<100mm	Good	Shape limited

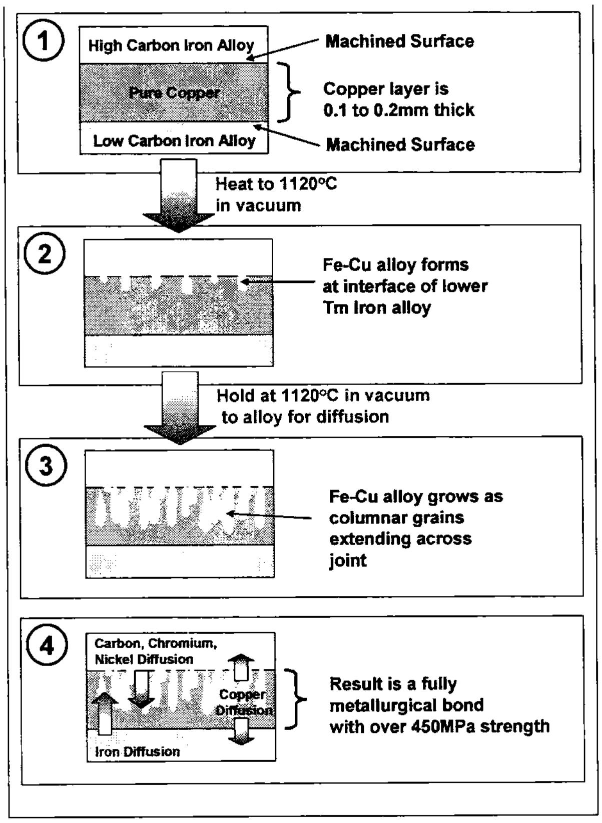

Figure 1. Schematic diagram of vacuum brazing process

The principal of the new vacuum casting joining process permits the white iron to be bonded to the steel in the absence of a brazing alloy. The temperature inside the vacuum furnace is increased until the melting point of the white iron is exceeded, resulting in the white iron wetting the surface of the steel substrate.

2. COMPOSITE MANUFACTURE

A range of white iron/steel composites have been successfully manufactured using the new vacuum casting process, and the basic process involves the following:

- Bring the lower melting point white iron alloy to +50°C above it's liquidus temperature;
- By excluding oxidation the liquid alloy can wet the surface of the substrate;
- the liquid/solid interface locally dissolves the alloy substrate
- upon cooling the metallurgical bond is produced, and diffusion of elements can occur across the interface

The dissolution of the steel substrate by the liquid white iron is diagrammatically shown in Fig 2.

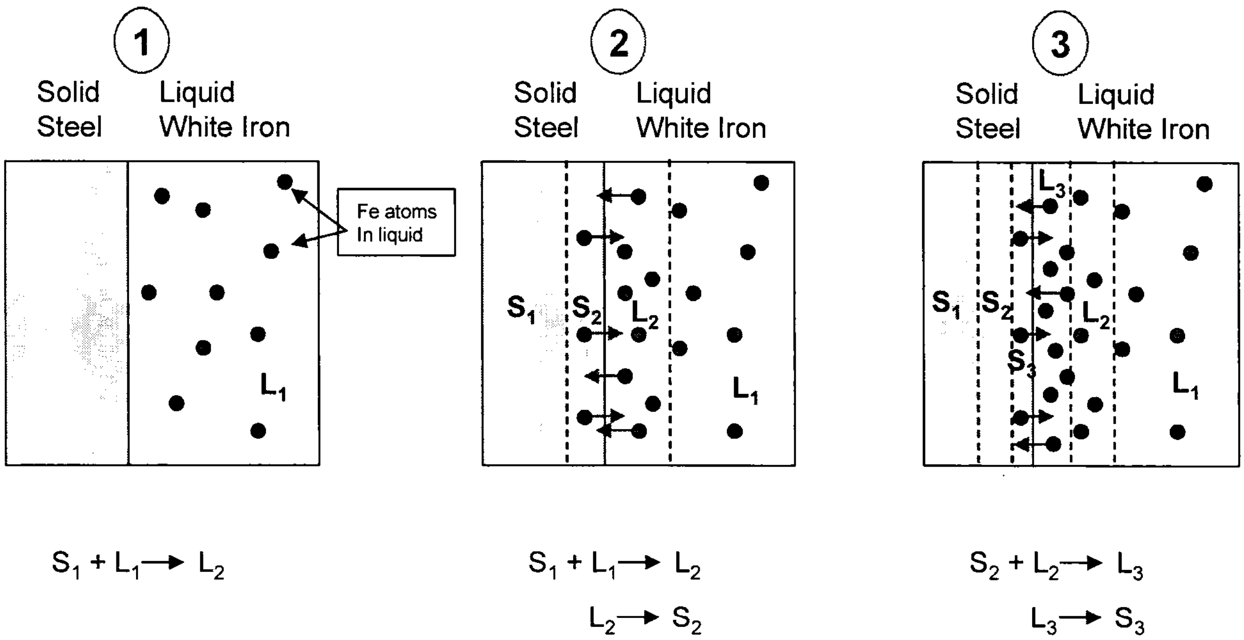

Figure 2. Schematic diagram of solid/liquid interface during vacuum casting

When the white iron is molten and initially in contact with the steel substrate (solid), the liquid alloy will start to dissolve the solid, and principally iron is dissolved into the liquid alloy. The increase in iron into the liquid alloy produces a locally rich liquid zone in the absence of any stirring or relative velocity of liquid metal. In the Fe-Cr-C alloy system, when the percentage of iron increases in the white iron, the melting point of the liquid increases.

Hence locally at the solid/liquid interface, the melting point of the liquid increases, and hence some solidification of this new composition will occur, albeit for only a relatively small period as the bulk of the material adjacent is still liquid.

The remaining liquid then begins to dissolve the adjacent solid, which is now of a slightly different composition to the original steel. The process continues producing a gradual dissolution of the steel substrate into the liquid white iron.

Parameters such as soak temperature, soak duration, white iron composition, cleanliness of the original steel substrate, vacuum pressure, etc. all have an influence on the resulting bond.

3. INTERFACE ANALYSIS

In order to improve the understanding of the bonding process and transport mechanisms, a significant amount of research has been conducted on the bond interface. Techniques that have been used to analyse the interface include optical microscopy, microhardness profiles, scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), and quantitative x-ray mapping (QXRM).

SEM analysis was performed on a JEOL 35CF with the Moran Scientific X-ray mapping (XRM) system using the new multi-detector arrangement. All analysis was performed at 20kV accelerating voltage and the post processing of the x-ray maps was performed using the Moran Chemical Imaging software. A JEOL 733 microprobe was used to map the carbon distribution using the wavelength dispersive spectrometer (WDS).

The typical microstructure of the interface region is shown in Fig 3. There are four zones that can be defined within the interface region. Zone 1 is the parent white iron, which typically consists of complex chromium carbides supported within a ferrous matrix. Zone 2 is a carbide depleted region adjacent to the bond interface, with the composition of this phase typically the equivalent to the ferrous phase of the Zone 1 white iron alloy. Zone 2 has intergranular M_3C carbides which extend perpendicular to the interface. Zone 3 is the steel region adjacent to the bond interface, and consists almost entirely of the eutectoid transformation phase pearlite, with some intergranular M_3C carbides. Further away from the interface within the steel the original steel parent alloy is Zone 4.

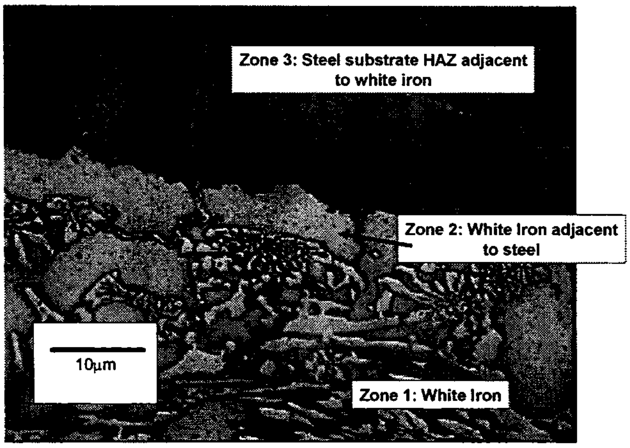

Figure 3. Optical micrograph of interface

SEM micrographs and x-ray maps of the interface region are shown in Fig 4, 5 and 6. The same zones described for the optical micrograph can be observed.

The x-ray maps show the iron and chromium gradients at the interface region, which supports the progressive solidification model described in Fig 2.

If the x-ray intensity for a given position on the map for specific elements is plotted against the x-ray intensity for another element (for example iron and chromium), a scatter plot can be established. The presence of alloy phases within the x-ray map will be shown by regions on the scatter plot that have high overlap. Use of colouring of these scatter plots can permit specific microstructural features to be isolated using a threshold method (see Fig 5). Selecting the area of position on the scatter diagrams allows us to replace these points with colour on the original x-ray map image. Hence, showing where phases are located.

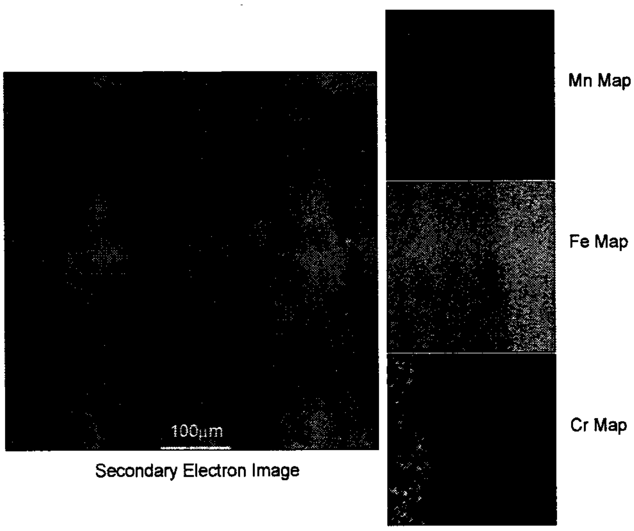

Figure 4. Secondary electron image and X-ray maps of interface

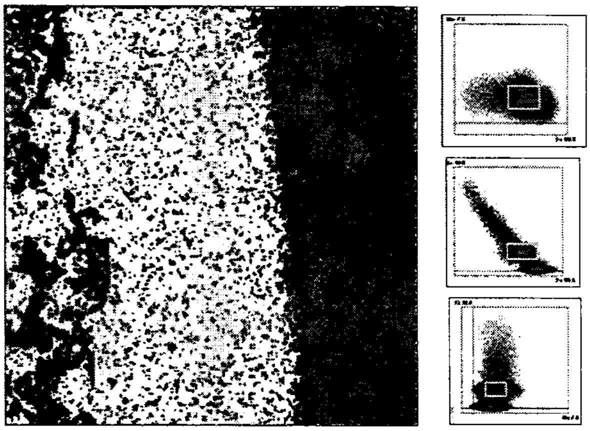

Figure 5. Scatter diagrams and highlighted compositional zone for interface

Once a specific phase region has been isolated, computer software such as the Moran Scientific package can be used to build a pseudo colour image of the interface region, providing a chemical image of the phases present in the micrograph. Fig 6 represents the pseudo colour map for the white iron/steel interface. The complex chromium carbides are represented by the red phase, the white iron ferrous matrix is represented by the dark blue phase, and the steel is represented by the yellow phase. The light blue phase shown is a iron rich zone adjacent to the interface within Zone 2 of the microstructure.

The benefit of utilizing quantitative x-ray mapping as an analysis tool is the ability to isolate and study discrete phases within the microstructure of the alloy, which would otherwise not be obvious through other analytical methods.

Additional x-ray mapping analysis has been previously published [2,3] that provides further detail on the vacuum cast composites.

Further work is continuing with the use of electron beam backscattered diffraction methods, and correlating these crystal structure maps with the quantitative x-ray maps for the same regions.

The presence of the liquid white iron adjacent to the steel during the vacuum casting process provides a high source of carbon that can readily diffuse into the steel, as with carburizing processes. A typical carbon intensity line profile for the vacuum cast interface is shown in Fig 7. It can be seen from the trend shown in the line profile that the carbon is progressively diffusing into the steel. This has also been confirmed optically by the high volume fraction of pearlite in the steel zone adjacent to the interface.

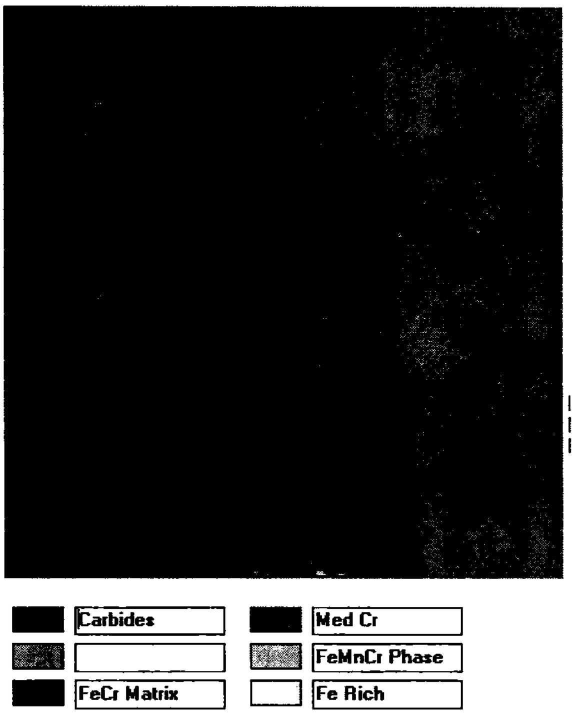

Figure 6. Chemical phase colour x-ray map of interface

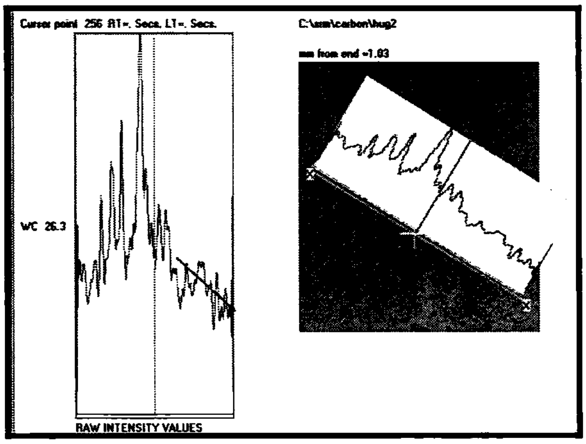

Figure 7. Carbon line profile for interface region. Defocussing of WDS has been taken into account.

4. FIELD TRIALS

A number of field trials have been conducted to test the performance of the vacuum cast composite alloy in mining conditions. The initial tests conducted have focused on applications associated with ground engaging tools (GET) used on large mining front end loaders. These front end loaders are typically used on Run Of Mine (ROM) Pad work, effectively loading mined ore into crusher feeder bins. The application would be considered of moderate impact and high abrasive wear.

Standard parts used for GET are manufactured from a chromium/molybdenum medium carbon steel which is typically used in the quenched and tempered condition.

The front of the bucket lip on the loader is fitted with disposable wear teeth (or bucket teeth). These bucket teeth can last anywhere from between 100 hours to 1000 hours operation depending on the individual mine site conditions, and make up a large proportion of the maintenance costs associated with the front end loaders.

The trials conducted as part of this study were conducted at an iron ore mine located at Koolyanobbing, approximately 50kms north-east of Southern Cross, Western Australia. The parts were installed on a CATERPILLAR 992 front end loader, and the bucket teeth would normally last approximately 250-300 hours of service. The CAT992 loader is shown in Fig 8.

Three trials were conducted as follows:

- Trial 1: White iron/ steel bucket teeth based on CSIRO Cast-Bond process[4]
- Trial 2: White iron/ steel based on new process
- Trial 3: White iron/ steel based on new process

Figure 8. CAT 992 Front End Loader
93 tonnes Operating Weight
63 tonnes Breakout Force

The arrangement of the original parts used for comparison to the new trial parts is shown in Fig 9. Note the use of other composite wear plates and bars along the front of the bucket to prevent gross wear of the bucket base lip. The normal bucket has an empty mass with the wear parts fitted of approximately 13 tonnes.

Figure 9. Original ESCO V61ELT bucket teeth

The first trial which used wear parts manufactured using the CSIRO Cast Bond process was stopped after approximately 100 hours operation due to cracking of the white iron component of the composite wear teeth.

Figure 10. Trial composite wear parts and ESCO V61ELT parts during trial. First tooth (bottom of image) is the composite part

The second trial used the composites manufactured from the new process. Fig 10 shows the wear of the composite parts after approximately 240 hours of operation. Note the original ESCO wear parts have experienced substantial wear whilst the composite wear parts (which were originally shorter than the ESCO parts) have substantial white iron alloy remaining.

Fig 11 shows the side profile of the composite wear parts after 240 hours of operation. Substantial thickness remains underneath the composite wear parts.

Trial 3 was a further trial of the new process composite parts, and resulted in excess of 700 hours wear life compared to the original steel wear parts. Site personnel at Koolyanobbing have confirmed the final life of the composite wear parts was three times the original steel parts.

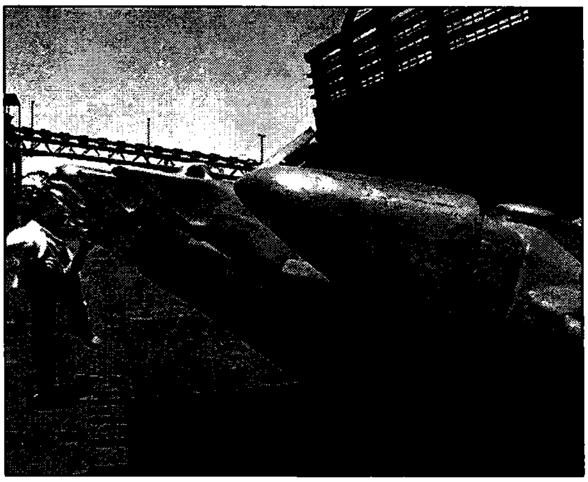

Figure 11. Trial composite wear parts during trial

5. CONCLUSION

A new vacuum casting process has been developed that permits composite white iron/steel wear parts to be manufactured for use in medium impact, high wear mining applications. The new process provides a method of manufacturing complex shaped composites that exhibit excellent bonding.

Analysis of the interface region using scanning electron microscopy and x-ray mapping methods has demonstrated full metallurgical bonding between the white iron and the steel substrate.

Field trials of parts manufactured using the new composite process have provided a substantial improvement in wear life when compared to the original steel wear parts.

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