

Material Matters

Tuff Stuff: Goulds Abrasion Resistant Irons

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Introduction

High chromium abrasion resistant cast irons used for pumping abrasive slurries are not well understood, and often misapplied. Abrasion resistant irons used in slurry pump applications tend to be a mix of compromised properties. Although chosen mainly for abrasion resistance, they can be tailored to provide unique properties, and offer practical solutions for some very corrosive and complex slurry environments.

While slurry pump materials must resist wear, they must retain strength and toughness against operational stress, and also provide some measure of corrosion resistance against chemical attack. Since there are different alloys that can be used, material selection is frequently based on finding the most economical material offering the best combination of properties, that satisfies the service and customer requirements.

Abrasion resistant irons can be supplied with distinct chemical compositions that affect the overall microstructure and metal properties. This connection between microstructure and properties also relates to service performance. Control of the metal structure is crucial if good wear life is to be achieved. It is chemical composition balance that determines alloy structure, metal properties, and performance in handling abrasive slurries.

Structure Affects Performance

All Goulds high chromium irons reviewed here are two-phase alloys consisting of a complex structure of chromium carbides embedded in a relatively tough and highly alloyed steel matrix. The carbides are hard and wear resistant, but also brittle. As a result, wear performance is directly related to the amount and nature of these carbides, as well as the overall hardness, toughness and resistance of the metal matrix to fracture and corrosion.

Under applied stress, the metal will plastically deform unless cracks initiate from the carbides. Once initiated, they can propagate rapidly through the matrix resulting in fracture. Permissible stress levels can be markedly raised, and fracture toughness improved, if these carbides are discontinuous, globularized and/or reduced in size and volume. To a large extent the metal matrix has the

characteristics of tool steel since graphite (normally found in irons) is not formed in high chromium alloys. The matrix provides toughness, carbide support and corrosion resistance against the environment; and like most alloy steel can be processed to further improve wear and fracture resistance.

The success of high chromium irons in abrasive slurries is attributed to the fact that the hardness of the iron-chromium carbide is greater than the minerals being pumped. High chromium content ensures the carbides form as the superior M_7C_3 type in austenitic and martensitic alloys, and as the $M_{23}C_6$ type in the ferritic alloys.⁽¹⁾ These carbides solidify as a discontinuous phase resulting in alloys that offer superior wear resistance, improved toughness and strength, compared to the lower chromium white irons.

The matrix can consist of austenite, martensite or even ferrite in some of the highest chromium alloys offered. While slurry pump materials can be furnished with satisfactory hardness in the as-cast condition, optimum hardness and wear resistance is ordinarily obtained after receiving a hardening or homogenizing process treatment. Lacking significant austenite stabilizing elements, high chromium iron castings normally transform under a stringent air-quench or controlled furnace cooling to develop their final microstructures. With proper composition selection and processing, the material properties can be optimized for a wide range of slurry services.

Slurry Alloy Wear Resistance

The erosive wear of pump parts is essentially the result of abrasive cutting or gouging away at the metal surface by minerals of varying hardness, size and shape. Wear occurs when minerals with higher hardness damage the softer metal matrix causing the carbides to either fracture, or fall out as the supporting matrix erodes and/or corrodes away. Improving both the erosion and corrosion resistance of the supporting metal matrix is crucial to increasing the material's performance.

The excellent wear resistance of high chromium iron is mostly due to the carbides which can show a volume fraction as high as 30 to 40% or more of the final structure. Testing various irons in abrasive slurries has shown that there is a direct relationship between wear rate and volume of carbide present. An alloy filled with discontinuous carbides in a fully martensitic matrix appears to offer the best wear resistant iron for abrasive slurry pump services. While wear rate generally improves with an increase in metal hardness and carbide volume, other microstructural features such as grain fineness; carbide size, shape and distribution; as well as

matrix alloy content must not be overlooked. As a final point, specialized heat treatments can result in some disintegration of larger carbides into more globular or spheroidized forms, and provide for the precipitation of smaller secondary carbides throughout the metal matrix. This can add an additional 5-10% carbide to the overall microstructure, with further improvement in wear resistance.

Slurry Alloy Corrosion Resistance

The abrasion resistant irons are not ideal for corrosion services because there are compositional and electropotential differences between the matrix and carbide phase, which destabilizes the alloy's ability to resist chemical attack. The localized potential differences can establish small galvanic corrosion cells that accelerate attack at carbide phase boundaries.

In more aggressive slurries the combined effects of corrosion and solids erosion accelerate the rate of material loss as protective passive surfaces are removed from the metal. The rate, which these protective surfaces are lost and restored, determines overall corrosion rate. Since stability of surface passivation is controlled by the amount of chromium in the matrix, it should be apparent that increasing chromium should significantly increase corrosion resistance.

By appropriate selection of chemical composition the metallurgical makeup of the alloys offered can be modified to suit particular service conditions. Combining this knowledge within a modern high alloy foundry allows Goulds the ability to offer a broad range of alloys for use in the mining and minerals processing slurry industries.

Differences in High Chromium Irons

To better understand the Goulds high chromium irons and their use, it should be recognized that the alloy differences are directly related to their composition and resultant microstructures. The carbon and chromium contents, which influence the amount of primary and eutectic carbides, have been chosen within each alloy to provide the most favorable combination of properties for various anticipated slurry conditions. Providing more chromium to the matrix by reducing carbon and carbide volume enhances corrosion resistance.

For a given chromium content, increasing the carbon content up to the eutectic composition results in an increased amount of eutectic carbide, with further increase resulting in the formation of coarse brittle primary carbides. Increasing the volume of carbides provides better abrasive wear resistance, but reduces

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toughness and corrosion resistance in all but the highest chromium ferritic matrix alloys. In other words, both the carbide phase as well as the matrix must be controlled to achieve the best combination of material properties.

The ferrite (α) liquidus and austenite (γ) liquidus boundaries of the iron-chromium-carbon phase diagram are illustrated in Figure 1. For alloys with compositions that fall below the right-side leg of the austenite eutectic boundary line (e.g. low carbon- 27Wt% chromium alloys), primary austenite forms the metallic matrix phase before eutectic ($L \rightarrow \gamma + M_7C_3$) solidification takes place. Such irons are referred to as "hypo-eutectic" because they form below (hypo means below or less than) the eutectic boundary line.

Higher chromium corrosion resistant irons (i.e. 35Wt% chromium alloys), can have a composition that falls above the left-side leg of the ferrite eutectic boundary line also shown in Figure 1. In the "hyper-eutectic" irons primary ferrite forms the metallic phase before the eutectic ($L \rightarrow \alpha + M_{23}C_6$) solidification occurs. These irons are referred to as "hyper-eutectic" because they form above (hyper means above or more than) the eutectic boundary line.

As carbon or chromium content is increased, the structure changes from "hypo-eutectic" to "hyper-eutectic" as we cross the eutectic composition boundary limits. Hyper-eutectic low chromium irons (not offered by Goulds and not discussed here) would contain coarse primary carbides in a matrix of eutectic carbides and other transformation products. While very abrasion resistant, hyper-eutectic irons are very brittle and seldom used in commercial pump applications.

The Goulds High Chromium Irons

Goulds Material Code 1228 (27Wt% chrome iron) is hypo-eutectic, and consists of a high volume of eutectic chromium carbides dispersed in a hardened and tempered martensitic matrix. This alloy offers an overall Brinell hardness of about 600 - 650 HB. It is our standard high chromium iron, which notably outperforms other commercially available white irons (e.g. the Ni-Hard and 15Chrome-3 Moly irons) in services where abrasion and mild corrosion are major concerns.

Alloy 1228 success in slurry applications is due to its relatively high matrix chromium content (near 11/12% by weight) with about 31% carbide by volume. The chromium rich ferrous matrix provides mild corrosion resistance somewhat similar to that of a 12% chromium martensitic stainless steel, while the carbide phase provides abrasion resistance. This alloy is suitable for a

wide range of slurries that are mildly corrosive (in pH range of 4.5 to 12), and useful where the slurries are generally more abrasive than corrosive.

The structure of Goulds Material Code 1269 (28Wt%chrome - lower carbon) is also hypo-eutectic, but consists of dispersed eutectic carbides in an austenitic and martensitic matrix. This is a modified 1228 iron that is basically a higher chromium - lower carbon alloy with added grain refining elements to improve toughness, corrosion resistance and strength. This differs from the standard alloy in that carbon content is reduced by about 1/3 with increased chromium. Bulk hardness drops to about 500 - 550 HB, but corrosion resistance considerably improves due to the additional levels of chromium added to the matrix.

Carbon reduction results in less carbide (reduced to 20% by volume) with less chromium tied up in the carbide phase. Thus the matrix of alloy 1269 is richer in dissolved chromium content (about 17/18% by weight) which greatly improves corrosion resistance. As a result, alloy 1269 offers superior corrosion resistance over a broader range of service conditions (pH range of 3.5 to 13.5), and is suitable for slurries requiring increased corrosion resistance with moderate abrasion resistance. This higher chromium iron offers a better overall combination of abrasion and corrosion resistance, toughness and strength.

Finally, with our Goulds Material Code 1650 (38Wt% chrome) alloy we have an iron offering 1/3 more chromium content than either alloy 1228 or 1269. This material has been designed for the most corrosive and severe slurry applications, and can offer the performance of a high alloy corrosion resistant stainless steel

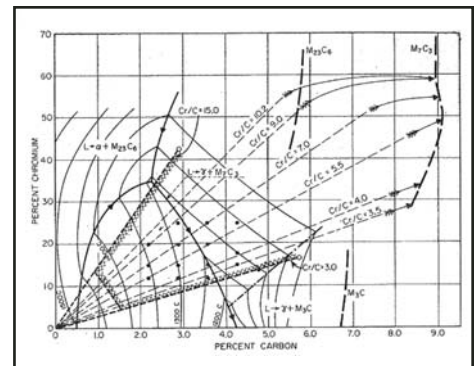


Figure 1. Section of iron-chromium-carbon ternary system illustrating the ferrite (a) and austenite (g) liquidus boundaries. (Source Ref. 1)

combined with moderate abrasion resistance. While the microstructure of 1650 is hypereutectic, this alloy consists of a relatively high volume of globularized eutectic carbides in a more corrosion resistant ferritic stainless steel matrix. Bulk hardness is reduced to about 400 - 450 HB in a non-hardenable ferritic stainless alloy, however, corrosion resistance is greatly improved due to much higher chromium levels. This alloy is the richest in dissolved matrix chromium (near 22% by weight), and maintains a high level of abrasion resistant carbides (about 30% by volume), resulting in a material that offers superior erosion and corrosion resistance.

Among the highest chromium abrasion resistant irons, the ferritic grades like alloy 1650 are used in the most demanding erosive-corrosive slurry environments. This alloy is suitable for many acidic slurry services having a pH of 2 or less, such as flue gas desulfurization and acidic gypsum or phosphate slurry environments. A good example of this alloy on an erosive-corrosive service is shown in Figure 2.



Figure 2. Goulds 8X10-29 Model 5500 Slurry Pumps in Goulds Alloy 1650 on an erosive-corrosive acid gypsum slurry transfer in Lakeland, Florida.

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SUMMARY

When selecting abrasion resistant irons, it is important to remember that high chromium cast iron castings are performance alloys that are tailored for demanding slurry environments. This basic overview and understanding of the main alloy differences should help ensure they are properly selected and applied in the environments for which they were designed.

Alloys selected for abrasion resistance should offer the highest hardness possible in a martensitic matrix. Tempering after hardening to achieve a tempered martensitic matrix greatly improves toughness and fracture resistance. As noted, abrasion resistance is improved by selecting an alloy with increased carbon and carbide volume, while toughness is improved by strengthening the metal matrix. Greater volumes of carbides are achieved by increasing

both the carbon and chromium level within the base metal.

While abrasion can result in premature wear of slurry pumps on its own, when it is also combined with a corrosive mechanism accelerated erosion-corrosion can be expected. Steps taken to lower the carbon content and increase the chromium will raise matrix chromium levels and improve corrosion resistance. Increasing chromium to the very highest solubility levels achieves a superior corrosion resistant ferritic alloy, which is best for more complex corrosive slurries.

Finally, the synergistic effects of abrasion and corrosion results in much greater wear than those where each mechanism is present alone. Therefore, one of the first considerations when selecting an abrasion resistant alloy for any

application is to determine if a corrosion mechanism will also be present, and to what extent corrosion will effect overall wear if combined with solids abrasion.

It is essential to recognize that conditions in one type of slurry may be completely different from another, requiring a different material selection altogether. When handling complex erosive-corrosive slurries, the best performance often is achieved by nothing more than having the right high chromium alloys matched to the specific service needs. ■

References:

1. MARATRAY, F and USSEGLIO— NANOT, R., "Factors Affecting the Structure of Chromium and Chromium-Molybdenum White Irons," Climax Molybdenum Publication, 1970

Service Solutions

Thai PRO Services Adds Valve Repair Capabilities

Scott Torgusson, A.P., Facility Manager
Thai PRO Services, ITT Industrial Products Group

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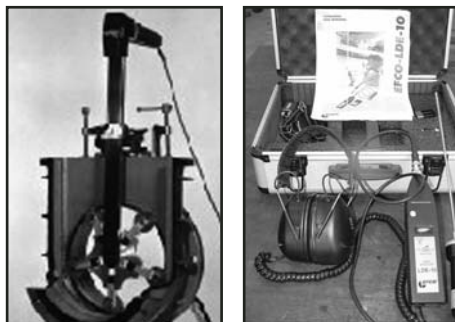
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Finding a Solution that Keeps the Process Running

Buddy Morris, Global Marketing Manager
Slurry Pump Operation – Ashland, PA

US Filter had installed a waste treatment process at the Merck Cherokee Plant in Riverside, PA. The pumps installed were 14" Axial Flow units in Cast Iron construction. Ashland-based field service had participated in the original start-up.

Six months after start-up, we received a call stating the amps had dropped on one of the pumps. On Tuesday Ashland field service went to the site to investigate. The pump was opened up and inspected. The pump had experienced severe corrosion and erosion even though the pumpage was supposed to be PH neutral with minimal, if any, solids. The cast iron props (impellers) were almost completely gone.

Merck was in a bind, as this was their treatment system. To shut it down would mean shutting down the plant. A spare was installed for the one unit, however, Merck did not have a back up for the second unit. All the pumps had been installed at the same time. If the other pumps went down, they would have to start shutting down the plant.

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