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Big Data Driven Materials Designed for the Mining Industry

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As the mining industry continues to evolve there is a need for materials innovation to keep pace with ever changing needs. In some cases there is simply a desire for fundamental performance improvement in materials which are used today. A common performance metric of the mining industry is wear resistance. One example of this paper will discuss improvements to wear plate alloys, specifically the development of Metco 8226, enabled via the big data techniques which make extraordinary increases in performance on the order of 2-6X over conventional materials. There is also an ongoing need to repair components cost effectively. This paper will describe the development of a Metco 8293, a material development to be utilized within the arc spray process to quickly and cost effectively re-build worn components such as engine decks. Both Metco 8226 and 8293 were designed using a proprietary software package known as the Rapid Alloy Development (RAD) platform. A variety of materials have been designed for the mining industry using RAD and to demonstrate the breadth of capability of advanced computational techniques these two products which are on opposite sides of the performance spectrum: Metco 8226 (designed to be hard) and Metco 8293 (designed to be soft) are chosen as examples.

Designing Metco 8226: A Wear Plate Alloy with 2 to 6 Times Longer Life

Materials are routinely pushed to the limits in the mining industry. Due to the immense volume of mined material that components see, abrasion resistance is a common requirement for materials performance. As an example, wear plate is used in critical areas such as liners for chutes, buckets, and trucks to provide enhanced abrasion resistance to material transport equipment. The need for extreme abrasion resistance over large areas has led to the development of chromium carbide overlays (CCOs). CCOs are Fe-based alloys which have a multiphase microstructure containing an Fe matrix with chromium carbide precipitates. The chromium carbide precipitates are much harder than the a hard steel alloy (1500 HV versus 500 HV) and thus provide the enhanced abrasion resistance to the alloy. As intuition would suggest, changing the alloy composition to produce more chromium carbides in the microstructure will enhance the abrasion resistance. Again intuitively, this can be achieved by adding more chromium and carbon.

However, there is an upper limit to how much the abrasion resistance can be enhanced with these simple alloy modifications which yield more chromium carbide. It is also true that increases in chromium and carbon will create larger and importantly longer chromium carbides in the microstructure. Such large and long carbides are known to embrittle the structure and at some threshold the alloy becomes so brittle that it cracks itself apart and can serve no industrial function. The CCO alloy which balances this abrasion resistance / cracking relationship is:

Fe:	Balance
Cr:	~25 wt.%
C:	~5 wt.%

Any additional Cr or C will create a material which is simply too brittle.

To make further advances to the simple Fe-Cr-C alloys, materials scientists use additional dopant elements such as Nb, Ti, and V. Such alloys are termed complex chromium carbides. Nb, Ti, and V are beneficial in two regards: 1) they tend to form carbides which are harder than chromium carbides, and 2) they tend to form carbides which are spherical as opposed to needle-like. Harder carbides are beneficial for wear resistance and the spherical carbides improve toughness. While the development of complex chromium carbides has indeed yielded improved wear plate materials, the majority of alloys in used today are far from optimized.

This lack of optimization is due to the increased complexity and thereby potential alloying possibilities that occur when the design space is expanded from a 3 element system (Fe-Cr-C) to a 6 or higher order element system (Fe-Cr-C-Nb-Ti-V-B…). It is possible if perhaps tedious to manufacture tens of alloys to fully investigate the Fe-Cr-C compositional space. However, the Fe-Cr-C-Nb-Ti-V-B contains at least 10,000,000 different alloy possibilities, an alloying space which is impossible to evaluate with experimental techniques alone.

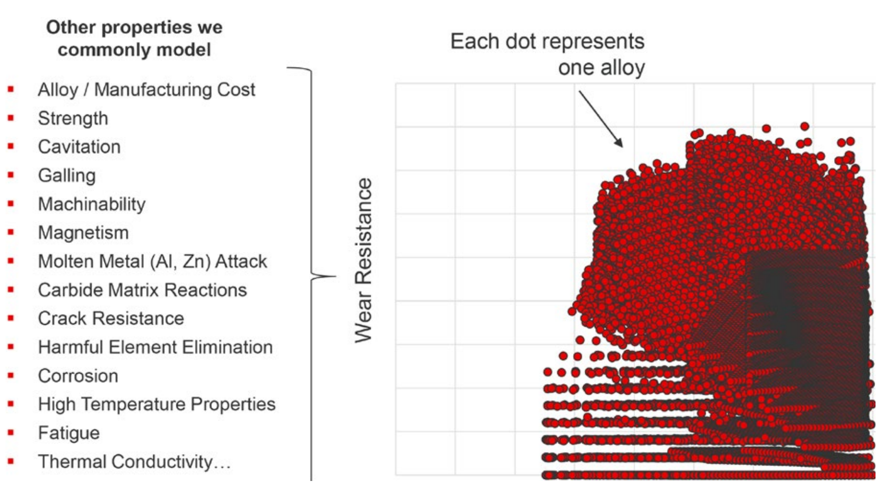

Figure 1: Visualization of Rapid Alloy Development (RAD) software employing big data mining techniques to identify new alloys with exemplary impact and wear resistance combined for wear plate applications. Also displayed is a list of other material properties which can be predicted via the RAD tool and to which are relevant to the mining industry.

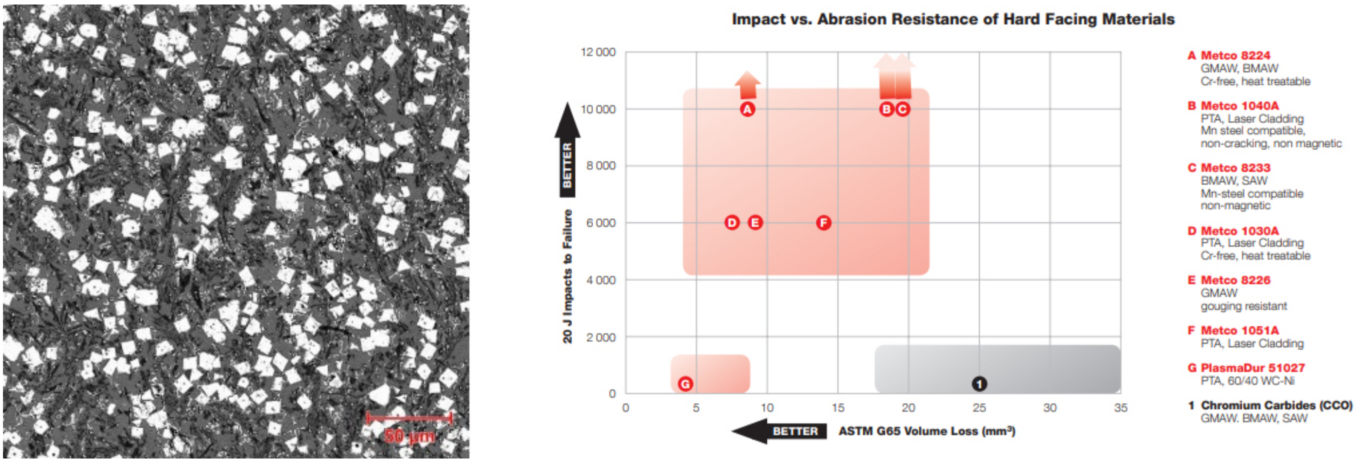

Figure 2: LEFT: Microstructure of Metco 8226 weld overlay showing fien scale precipitates of extremely hard Molybdenum borides (blocky white) embedded in a hard Martensitic matrix further containing hard carbides. RIGHT: A plot showing the unique property space of Metco 8226 and similarly RAD designed hardfacing materials in terms of combine abrasion and wear resistance.

Metco 8226 is indeed a complex alloy containing Fe, Cr, C, B, Mo and Nb whereby there are 100,000s of possible combinations. A technique which is capable of sorting through the potential combinations is required for a material scientist to make educated decisions about how to design such an alloy. The Rapid Alloy Development software, or RAD, was developed to accomplish this goal. The end results of the employed algorithms is shown in Figure 1, whereby all the alloys are positioned on the chart according to the key material properties of wear and impact resistance. Using such a tool, it is quite clear for a scientist to identify which alloy composition, represented by one dot in the diagram, achieves the desired performance goals.

Metco 8226 possess a unique microstructure, as shown in the leftmost plot of Figure 1, truly optimizing the goals intended of prior complex chromium carbide development efforts; a high fraction (> 40 %) of extremely hard carbide and boride precipitates (~2,600 HV) are present in the microstructure but the phases remain relatively small (10 to 50 µm). Such a microstructure enables Metco 8226 to operate in a unique property space of both increased abrasion and impact resistance as the rightmost chart of Figure 2 shows along with other hardfacing materials developed using this method. The lab test performance translates to a very unique performance in the field whereby Metco 8226 overlays typically survive 2 to 6 times longer than conventional CCOs.

In the wear plate example, wear and impact resistance are most critical. However, as Figure 1 illustrates many properties which are derivable from thermodynamics can be predicted and optimized via this tool including corrosion resistance, crack resistance, and even 'softness'.

Designing Metco 8293: Enabling Cost Effective Remanufacturing

In contrast to the wear plate example, the RAD tool can also be used to design materials which are uniquely soft. Metco 8293 was designed specifically for re-building worn components. In such examples, the restoration of the part dimensions is critical but the coating need not possess any unique performance properties. It is simply desirable for the coating to be applied as cost effectively and rapidly as possible.

In such remanufacturing applications it is today common to use standard steel materials or Ni-Al alloys. Steel materials are certainly cost effective from a materials cost perspective but tend to suffer from oxidation during the spray process and tend to form relatively hard coatings. The poor oxidation resistance of steel alloys creates a heavily oxidized coating which in turn has poor adhesion strength and limits the thickness and complexity of the parts which can be sprayed. Furthermore, a hard steel coating cannot be machined and typically must be ground. Grinding, as opposed to machining, increases the total cost of the applied coating. The coating properties of conventional steel alloys make them less attractive for many remanufacturing applications despite the low raw material cost. In such cases, Ni-Al type alloys are used despite the increased raw materials cost.

Metco 8293 was designed using the RAD platform specifically for arc spray considering in the design the thermodynamics of ox-

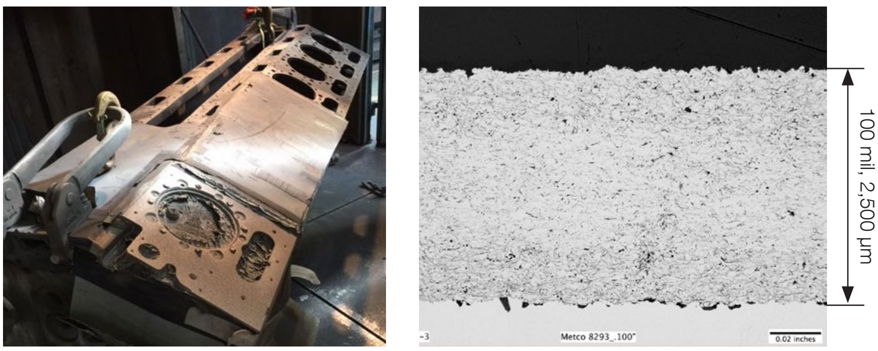

Figure 3: LEFT: A photograph of Metco 8293 sprayed via traditional arc spray 10 mm thick onto a worn engine block RIGHT: Micrograph of Metco 8293 coating highlighting microstructure relatively free of oxides sprayed to 2,500 µm thick

idation during spray and the desire for an adherent coating which could be machined easily. Similar to the wear plate example, Metco 8293 is a combination of 5 elements, Al, Cr, Ni, Si, and Fe which cannot effectively evaluated through experimental means. To eliminate oxidation of the steel alloy itself, the thermal spray wire was alloyed with elements that would preferentially oxidize allowing the desired steel alloy to remain relatively unaffected by the spray process. The rightmost image of Figure 3 shows a microstructure relatively free of large oxides that would otherwise reduce the adhesive properties of the coating and prevent such a thick (2,500 µm) coating from adhering to the workpiece. The composition was further controlled in such a way that it formed a stable austenite phase (the softest form of steel) regardless of cooling rate. The austenite structure of the coating allows this steel alloy to be easily machinable in comparison to many other steels.

The improved oxidation behavior and the stable austenitic phase structure of the material enable remanufacturing possibilities beyond even the capabilities of Ni-Al coatings. It is typical for thermal spray coatings to generally see lower adhesion as the coating becomes thicker which equates to a maximum allowable thickness of ~50 mils (1250 µm). Metco 8293 can be used to rebuild surfaces to as thick as 10 mm such as completed for the engine deck re-build shown in the leftmost image of Figure 3.

Conclusion

Mining applications require materials with a wide range of materials properties ranging from ultra-hard abrasion resistance alloys to soft materials which can themselves be easily machined. In all cases, the industry can benefit from targeted materials design to meet the specific performance requirements. Historically, it was too time consuming and costly to design alloys according to custom needs in this way and 'off the shelf' materials are simply used. However, with the growth of computational metallurgy and the development of big data tools such as the Rapid Alloy Development platform, materials can be quickly and cost effectively designed to better address industry and application needs. Such RAD-designed products can both make components last longer and to even repair them when they eventually wear out. ■■■

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