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Engineering the optimal balance of hardness & toughness for mining equipment wear parts

For decades, designers of mining equipment have struggled to balance hardness and toughness in their products.

It may sound as if they should go together. After all, what mining engineer wouldn't want a material that's both super hard and super resistant to cracking?

In practice, however, they are almost mutually exclusive: they pull in opposite directions, and that trade-off shows up constantly in mining wear parts such as mill liners. In addition, finding that right balance may vary from one application to another.

So, what's the difference?

hard
vs
tough

Hardness describes a material's resistance to local plastic deformation, such as indentation, scratching, gouging, and micro-cutting. In abrasive mining environments (ore, rocks, slurry, and entrained sand), hardness is highly valuable because most wear mechanisms are driven by sharp particles that plow, cut, or grind away the surface. As a result, increasing hardness reduces the abrasive wear rate because it becomes harder for particles to penetrate the surface and remove material.

Toughness, on the other hand, is about how much energy a material can absorb before it fractures. It indicates resistance to crack initiation and propagation, both of which are important when your component is subjected to impact loading, vibration, and cyclic stresses. In mining, of course, impacts are everywhere. Dropped rocks. Charge impacts in mills. Tramp metal events. Uneven loading. A very tough alloy can deform slightly, blunt cracks, and withstand these shocks without catastrophic failure.

Finding the optimal balance requires tradeoff

So why does improving one come at the expense of the other? A lot comes down to microstructure. Many of the things we do to make steel harder, such as increasing carbon, forming more carbides, or creating high-strength martensitic structures, also tend to make it less forgiving.

Hard microstructures often exhibit lower ductility and can concentrate stress at microstructural features such as carbide particles, inclusions, or prior-austenite grain boundaries. Under impact, those stress concentrations can generate cracks. Once a crack starts on a very hard/brittle microstructure, it spreads. There's also a practical consideration: mining wear isn't purely abrasion or purely impact, it's often impact-abrasion. You might need a hard surface to prevent gouging, but if the alloy is too brittle, it can chip, spall, or develop a network of cracks. When that happens, the surface can lose material faster than it would if it were a slightly softer, tougher alloy. Chunks break away rather than slowly wearing down.

That's why the "sweet spot" is application-specific. In a low-impact, high-abrasion situation (for example, certain slurry transport zones), you can optimise for hardness. However, in a high-impact use (SAG mill feed zones, lifter bars, and bucket teeth encountering large rock), you need a bit less hardness and want higher toughness and crack resistance.

Modern alloy development aims to achieve the best of both worlds by refining grain size, controlling carbide size/shape/distribution, strengthening the matrix without making it brittle, and using heat treatment to achieve the right balance.

The goal isn't "max hardness" or "max toughness." Rather, you want the best of both worlds. Enough hardness to resist wear. And enough toughness to consistently survive impacts over real operating cycles. And that will vary by application. There's also the practice of hardfacing.

Hardfacing

Hardfacing is one of those "workhorse" solutions in mining wear protection. It's widely used, often effective, and occasionally misunderstood.

In simple terms, hardfacing means applying a layer of very wear-resistant material (usually by welding) onto a tougher base component. The idea is to achieve a hard, abrasion-resistant surface where wear occurs, while the underlying steel provides the toughness and structural support you need.

Hardfacing can be an excellent tool when the wear mechanism is well understood and the process is tightly controlled.

But it's not a cure-all. You're adding processing steps and cost. Plus, the possibility of weld-related failure modes.

That's also why alloys that deliver high wear resistance without hardfacing are so attractive. You'll have fewer steps, fewer variables, and more predictable performance.

Hardfacing benefits

- **Better wear resistance where it matters most.** You can apply the hard layer only to high-wear zones (leading edges, lips, high-wear regions), a practical way to extend service life without changing the entire component design.
- **Cost-effective life extension (in the right cases).** For larger, more OPEX-intensive parts, rebuilding by hardfacing can be more cost efficient than replacement, especially when the base structure is still sound.
- **Fast customisation and "field tunability".** You can choose different consumables (high-chrome carbide, martensitic alloys, tungsten carbide types, etc.) depending on whether you're fighting abrasion, erosion, or gouging. Many sites also like that repairs can sometimes be done locally.
- **Maintains a tough core.** When done correctly, you end up with a tough substrate that absorbs impact and a hard skin that resists wear. It's one obvious way to manage the hardness/toughness trade-off.

Hardfacing limitations

- **Cracking can be a problem.** Many hardfacing deposits are so hard that they form stress-relief cracks as they cool. Sometimes those cracks don't immediately cause failure, but in impact or cyclic loading, they can become pathways for chunking, spalling, or rapid crack propagation. Especially if cracks extend into the base metal.
- **Dilution and inconsistency.** The chemistry and hardness of the hardfaced layer can vary depending on welding procedure, heat input, bead pattern, operator technique, and dilution from the base metal. Two "identical" hardfacing jobs can perform very differently in the field.
- **Heat-affected zone (HAZ) risks.** Welding changes the microstructure of the base metal near the weld. If preheat/interpass temperature/post-weld cooling aren't controlled, you can end up with a brittle HAZ, producing residual stresses, distortion, or reduced toughness right where you don't want it.
- **Not always great under impact-abrasion.** In high-impact zones, very hard overlays can chip or delaminate. If the wear mechanism includes heavy impacts, the failure mode may shift from gradual wear to sudden material loss.

R&D in action: Developing the optimal alloy starts with our customers

A South African iron ore operation approached FLS after achieving only two weeks of service from excavator-bucket teeth. For FLS's R&D team developed three candidate chemistries using casting and micro-alloying techniques and conducted 38 controlled experiments through an FLS foundry. For scalability, the team cast thick section samples (300 mm x 300mm x 300mm) and tested to replicate the results on thick section parts.

The team then combined the three alloys to create a single optimised alloy composition that delivers three times the wear life and requires no hard facing.

The process

The R&D team developed these advanced alloy systems by optimising chemistry and processing strategies, including controlled solidification, heat treatment, and alloying with carbon, nickel, chromium, molybdenum, vanadium, and other elements to refine carbide morphology, enhance matrix toughness, and promote secondary hardening.

Deoxidation

As the steel is cast, it absorbs oxygen and nitrogen from the atmosphere. As a result, we needed to remove those elements from the steel because they will make the final casting more porous, weakening its structure.

During that deoxidation process, we regulate the temperature to refine grain structure just right with FLS's proprietary grain refinement process:

- If the temperature is too low, the metal will not flow well, and you will not get a solid casting.
- If the temperature is too high, the grains will be too coarse, weakening the castings' properties.

The team conducted multiple tests to determine the optimal temperature for the deoxidation step. The resulting process controls in the deoxidation process were used to optimise grain formation.

When deoxidation is complete, the molten metal is poured into sand molds.

Cooling

The team discovered that they could not force the cooling process—removing the castings from the sand molds too quickly would cause cracks.

The critical element was heat treatment.

Heat treatment

During heat treatment, you manipulate the structure or the phases of the material to get the hardness and toughness needed.

The team identified phase transformations at specific temperatures, indicating changes in alloy structure during heating and cooling. Understanding these transformations helped FLS tailor the alloy's hardness, toughness, and wear resistance for mining applications.

The new KP30 alloy requires two heat-treatment steps:

1. Normalising: Heating the metal to a specific temperature and then cooling slowly to relieve manufacturing stresses and achieve the fine grain structure that provides the higher toughness required in the final material.

2. Tempering: A two-stage process. In this step, the team balances time and temperature to avoid removing hardness (Typically, each tempering stage reduces hardness). They fine-tuned the tempering process to prevent loss of hardness, aiming to distribute fine carbides throughout the microstructure.

Final Inspection

Finally, the material is inspected with destructive and nondestructive testing methods to ensure the product meets the required hardness and toughness for the application.

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KP30 alloy is born: Proven performance in the lab, to field testing and beyond

Heartened by the results, the team quickly moved beyond bucket teeth to other applications. Especially the grinding circuit and SAG mill liners, where the innovative FLS research saw even more positive results after field testing.

KP30 is already deployed in SAG mill shell liners and lifters, where it has shown **up to 30%** better wear life than standard alloys.

We've even dropped a wrecking ball onto KP30 – 10 times. And the results spoke for themselves that this innovative alloy can withstand the harshest conditions.

Final words: KP30 – Designed for miners, by miners

KP30 is a specialised alloy developed for applications that demand high wear resistance, toughness, and reliable performance under impact loading in mining operations. Alloy properties can be tuned for specific mining applications through heat treatment and composition adjustments.

After testing in the lab and in the field, we've seen a significant improvement compared to standard alloys that are already in operation. The result? Up to 30% longer wear life, plus other benefits that come with it.

It is no secret – KP30 is a step above and we look forward to changing the industry dynamic of what limits can be pushed.

Technical details

The KP30 alloy can be tuned to the duty by distributing fine carbides and adjusting heat treatment:

- **Hardness window (BHN):** 350–410; 410–470; 470–550**
- **Impact energy at 20°C:** ~30 J*

* Target hardness and impact properties are tailored by heat treatment and alloy optimisation.

** Final hardness depends on casting cross-section and heat-treatment route.

Interested in finding out how FLS KP30 can be integrated into your flowsheet to bring the value outlined in this whitepaper?

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