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The Science of Cost-Effective Materials Design – A Study in the Development of a High Strength, Impact Resistant Steel.

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Intermediate alloy steels are widely used in applications where both high strength and toughness are required for extreme/dynamic loading environments. Steels containing greater than 10% Ni-Co-Mo are amongst the highest strength martensitic steels, due to their high levels of solution strengthening, and preservation of toughness through nano-scaled secondary hardening, semi-coherent hcp-M_2C carbides. While these steels have high yield strengths ($\sigma_{y0.2\%}$ >1200MPa) with high impact toughness values (CVN@-40 >30J), they are often cost-prohibitive due to the material and processing cost of nickel and cobalt. Early stage-I steels such as ES-1 (Eglin Steel) were developed in response to the high cost of nickel-cobalt steels and performed well in extreme shock environments due to the presence of analogous nano-scaled hcp-$Fe_{2.4}C$ epsilon carbides. Unfortunately, the persistence of W-bearing carbides limited the use of ES-1 to relatively thin sections. In this study, we discuss the background and accelerated development cycle of AF96, an alternative Cr-Mo-Ni-Si stage-I temper steel using low-cost heuristic and Integrated Computational Materials Engineering (ICME)-assisted methods. The microstructure of AF96 was tailored to mimic that of ES-1, while reducing stability of detrimental phases and improving ease of processing in industrial environments. AF96 is amenable to casting and forging, deeply hardenable, and scalable to 100,000kg melt quantities. When produced at the industrial scale, it was found that AF96 exhibits near-statistically identical mechanical properties to ES-1 at 50% of the cost.