INCREASING THE LIFE CYCLE OF BUCKETS FOR WHEEL LOADERS USING HIGH STRENGTH AND ABRASION RESISTANT STEELS MICROALLOYED WITH NIOBIUM

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Abstract

CBMM applied niobium microalloyed steels in two types of buckets for wheel loaders operating at its facility in Araxá, Brazil. The objective was to evaluate the benefits of these steels relating to cost reduction, productivity and component life cycle. One of the analyzed loaders collects hot pieces of ferroniobium after ingot stripping and loads them into crusher silos. The use of wear resistant and tool steels solved the problems of deformation, wear and cracks during service, increasing bucket life by about 190%. The other machine was a wheel loader operating at the niobium ore mine. The new design with wear resistant and high strength steels reduced bucket weight by 14%, with a corresponding increase in load capacity. The extra capacity made loading the 42-tonne mine trucks more efficient. With the new materials, the cracks that previously occurred in the wheel loaders' buckets were eliminated, while the same wear resistance of the original chromium carbide clad steel was retained. Furthermore, investment costs were reduced by over 7%.

Introduction

CBMM strives to provide niobium technology to develop applications where this element can help to overcome the key challenges faced around the world: to achieve economic growth wisely and sustainably. In order to accomplish this, CBMM employs a technical group that works with steelmakers, research universities, institutes and end users. This technology program sponsors the development of materials that minimize raw material consumption by increasing component life cycles and optimizing process efficiencies to save energy and raw materials. A component of the program includes testing concepts developed on equipment operating at CBMM facilities in Araxá, Brazil.

Higher strength and more wear resistant steels are critical to create structures that have longer service lives, and to use less material in components that must withstand harsh working conditions. The loaders for different operations at CBMM facilities in Araxá face many challenges since they work in abrasive conditions, suffer oxidation and, in some cases, are subjected to high temperatures.

The lightweight design concept has been very well developed for different applications [1-5]. Niobium is particularly effective in simultaneously increasing the strength and toughness of steel, and now there are many papers reporting niobium's effect on wear resistance as well [6-7]. By increasing steel strength, it is possible to use thinner components, with corresponding reductions in weight. Since toughness is also increased, structural integrity is improved. As bucket weights decrease, loading capacities increase, leading to gains in operational efficiency.

The principal driver for this development was to improve the service life of the buckets and their loading efficiency, by applying high strength and wear resistant steels in the form of niobium microalloyed steels. This paper provides two examples of bucket loaders using these steels and the resulting benefits.

Description of the Two Case Study Wheel Loader Buckets Operating at CBMM Facilities

Stripped FeNb Ingot Loading Bucket

After being processed in electric arc furnaces, liquid ferroniobium (FeNb) is cooled in molds. Following solidification, the FeNb is stripped from the molds and collected by a loader for crusher feeding, Figure 1. During this transport operation, the FeNb can be at temperatures of up to 350 °C.

Figure 1. Loader collecting FeNb after ingot stripping.

FeNb remains in the bucket for no longer than ten minutes, but because the material is hot, the buckets suffer temperature-related deformation, Figure 2, and cracks, Figure 3.

Figure 2. Bucket deformation after 200 hours in service.

Figure 3. Bucket cracking after 200 hours in service.

The average service life of this kind of bucket had been 320 hours, with the best performance reaching 570 hours. The new bucket was developed to increase service life, and eliminate the cracking and deformation that makes it very difficult to collect FeNb from the floor.

Niobium Ore Loader Bucket

The second bucket developed was for wheel loaders transporting niobium ore at CBMM's mine, Figure 4. The main problem with the original bucket was the appearance of structural cracks, Figure 5. Service life for these components is reduced by such cracks since they start to appear at 1,600 to 2,000 hours. The goal is to achieve total service life over 11,000 hours. The wheel loaders' buckets experience very little wear, this only being important for the ground engaging tools (GET). GET wear will not be addressed in the current paper.

Figure 4. Wheel loader bucket at niobium ore mine.

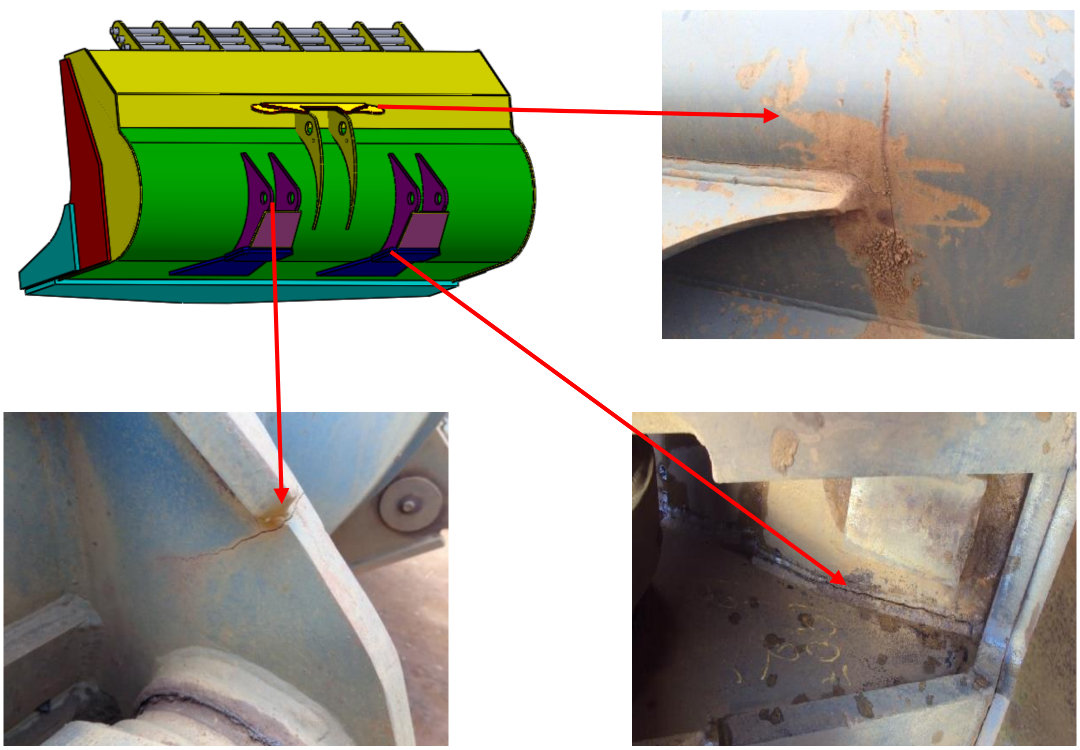
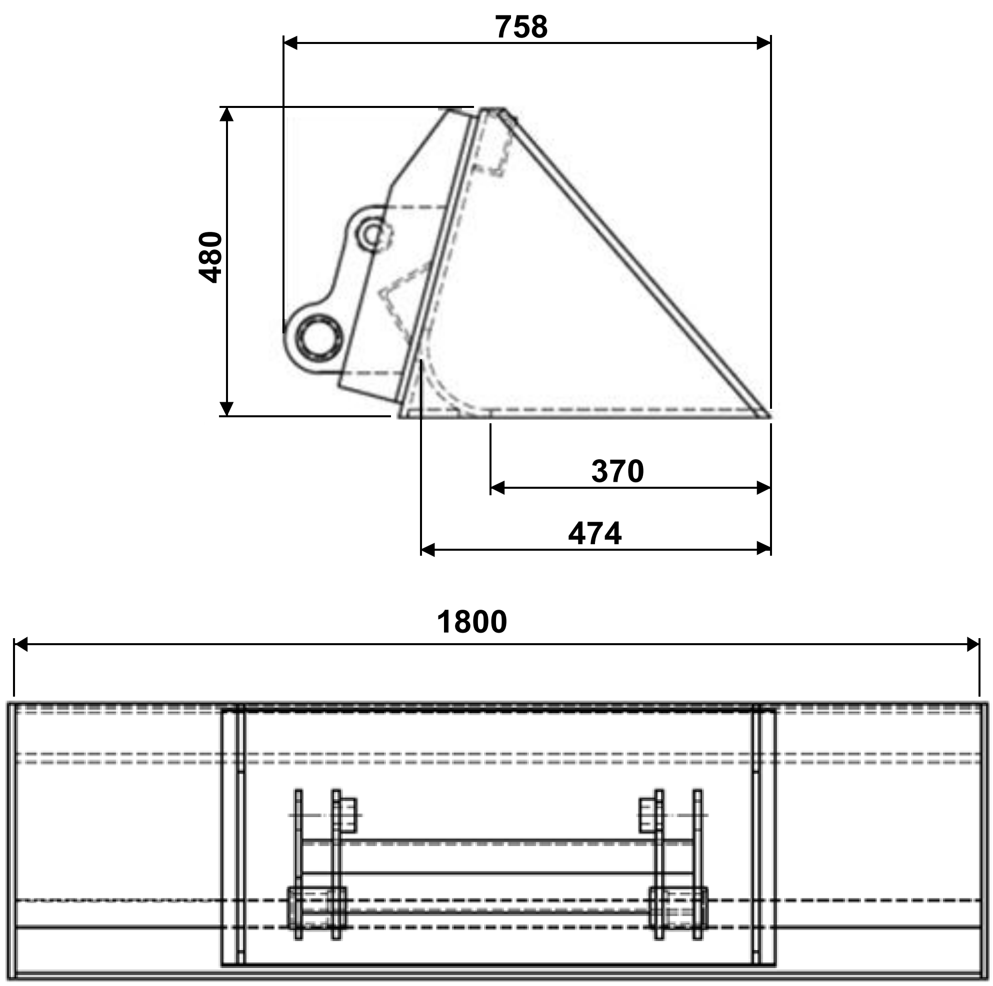


Figure 5. Structural cracks in the ore loader bucket after 2,000-3,000 hours of work time.

Materials and Description of the Developed Components

<u>Stripped FeNb Ingot Loading Bucket</u>

Figure 6 shows the bucket design, including selected dimensions. The bucket weighs about 364 kg and has a load volume of 0.24 m^3. The original model was made with carbon steel grades, Figure 7. Because microalloyed steels were used in the new bucket, the purchase cost was 42% higher than the original model. This investment must achieve payback through increased service life and lower maintenance.



Weight = 364 kg and volume = 0.24 m^3

Figure 6. Main dimensions (mm) of the stripped FeNb ingot loading bucket.

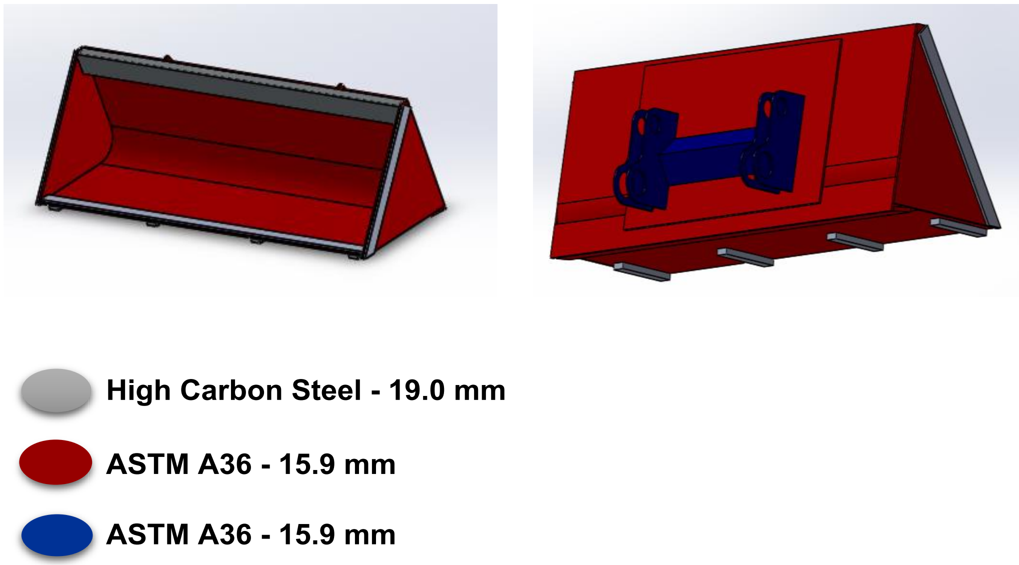
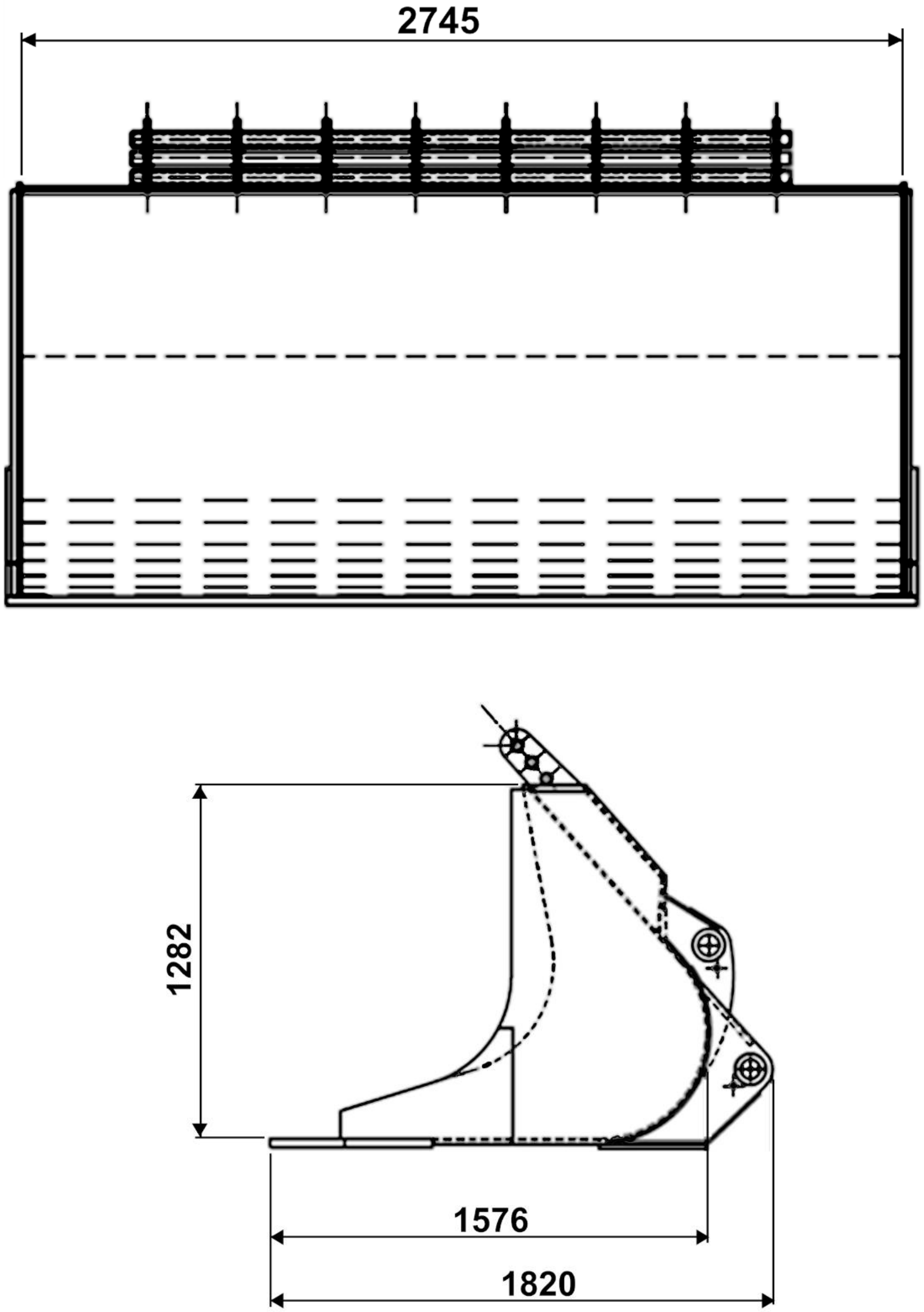


Figure 7. Steels used in the original stripped FeNb ingot loading bucket.

<u>Niobium Ore Loader Bucket</u>

Figure 8 shows the design and selected dimensions of the bucket used for the ore. The bucket weighs about 3,508 kg and has a load volume of 4 m^3. This bucket was originally made with carbon steel grades and the internal face was plated with chromium carbide, Figure 9. The trucks have a 42-tonne capacity to haul niobium ore from the mine to the ore conveyor belt that links to the homogenization yard. The original buckets had a 10,370 kg capacity per manufacturer specifications. Since it is impossible to achieve the maximum allowed load in real working conditions, more than four bucket loads were necessary to fill the truck. Therefore, an increase in bucket capacity to achieve loading the truck with four buckets would be highly beneficial.

The investment cost of the original bucket was US$20,606 per unit.



Weight = 3,508 kg and volume = 4 m^3

Figure 8. Main dimensions (mm) of niobium ore loader bucket.

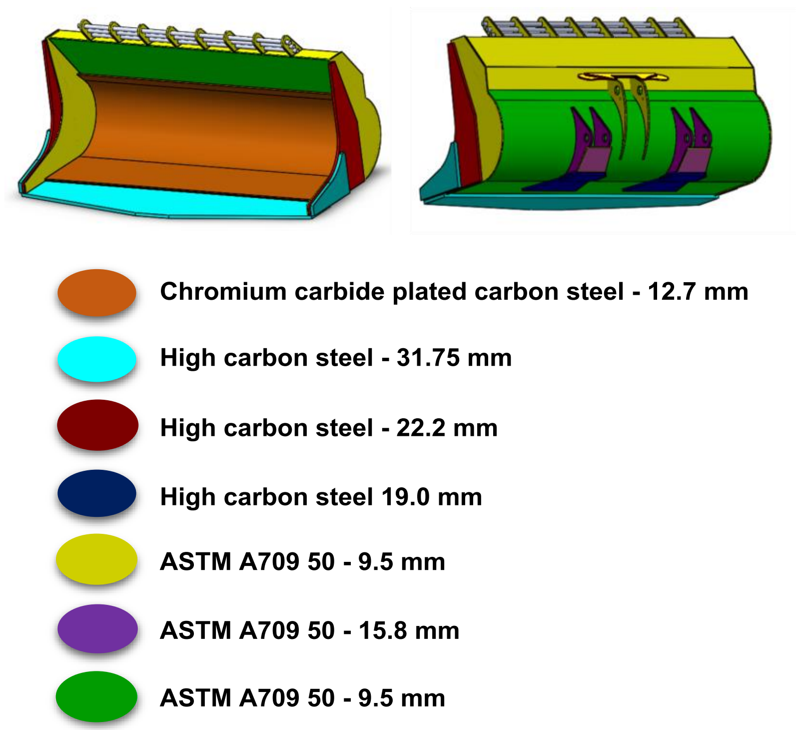


Figure 9. Steels used in the niobium ore loader bucket.

Steels

Table I presents the chemical compositions of the steels used in the old and new bucket designs. Table II shows the typical mechanical properties of the steels [8].

Table I. Steels Used in Bucket Structures

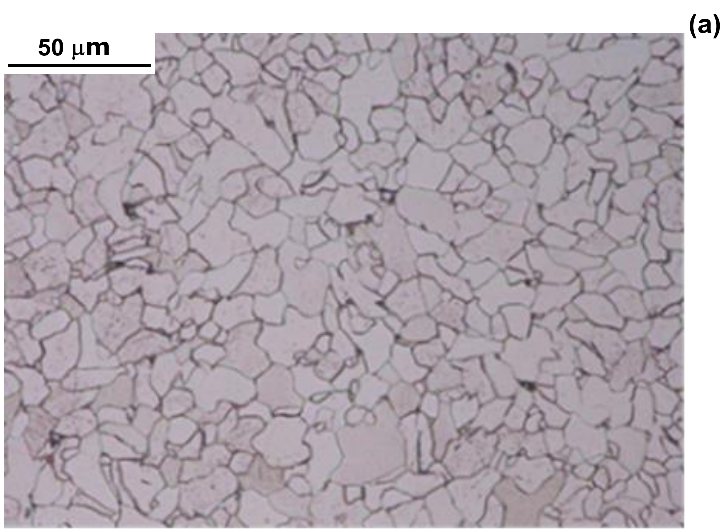
Steel	C	Si	Mn	P	S	Cr	Ni	Mo	Other	Nb
ASTM A36	0.25	0.50	1.70	0.035	0.035	-	-	-	-	-
High carbon steel	0.32	0.40	1.50	0.03	0.015	0.80		0.40	B - 50 ppm	-
ASTM A709 50	0.23	0.40	1.35	0.04	0.05	-	-	-	Cu - 0.20	-
Tool steel for plastic mold	0.26	1.08	0.80	0.008	0.004	1.35	0.66	0.80	V - 0.14	0.015
Structural steel YS >700 MPa	0.063	0.062	1.79	0.017	0.003	-	-	-	V - 0.010	0.060
Wear resistant steel	0.16	0.21	1.37	0.011	0.003	0.15	0.10	-	B - 0.001	0.012
High strength structural steel with good welding properties	0.15	0.30	1.20	0.012	0.003	0.30	0.10	0.15	-	0.011

Table II. Typical Mechanical Properties of Applied Steels [8] (ASTM and NBR Standards)

Steel	YS (MPa)	TS (MPa)	Hardness (HRC and HB)
ASTM A36	270	550	-
High carbon steel	450	550	360 – 400 HB
ASTM A709 50	345	450	-
Tool steel for plastic mold	1,300	1,450	45 HRC
Structural steel with YS >700 MPa	765	810	-
Wear resistant steel	1,270	1,450	450 ~ 500 HB
High strength structural steel with good welding properties	650	930	-

The microstructures of the steels are shown in Figures 10-12. The high strength structural steel has a ferritic microstructure with some pearlite, but with a very fine grain size that guarantees higher mechanical strength compared to the carbon steel grades, Figure 10. The tool steel and the wear resistant steel have tempered martensite microstructures with fine carbides, which ensures their wear resistance capacity, Figure 11. The high strength structural steel chosen for its good weldability has a similar microstructure of tempered martensite.

The tool steel and the wear resistant steel have much higher yield and tensile strengths compared to the other materials, having a specified hardness to guarantee wear resistance, Table II.



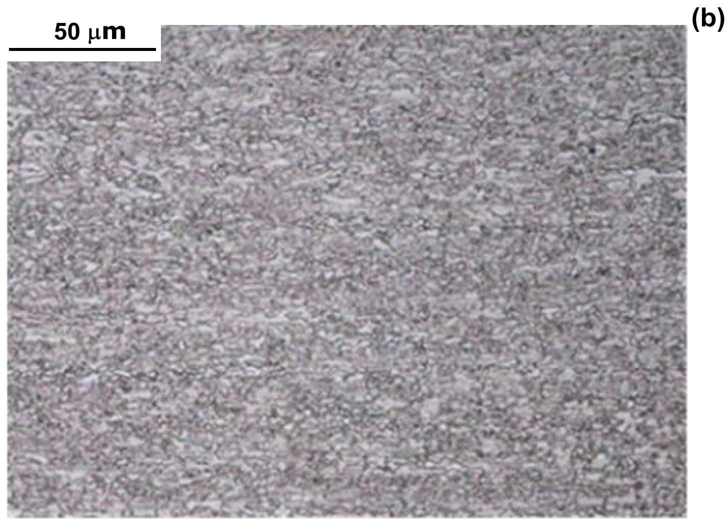
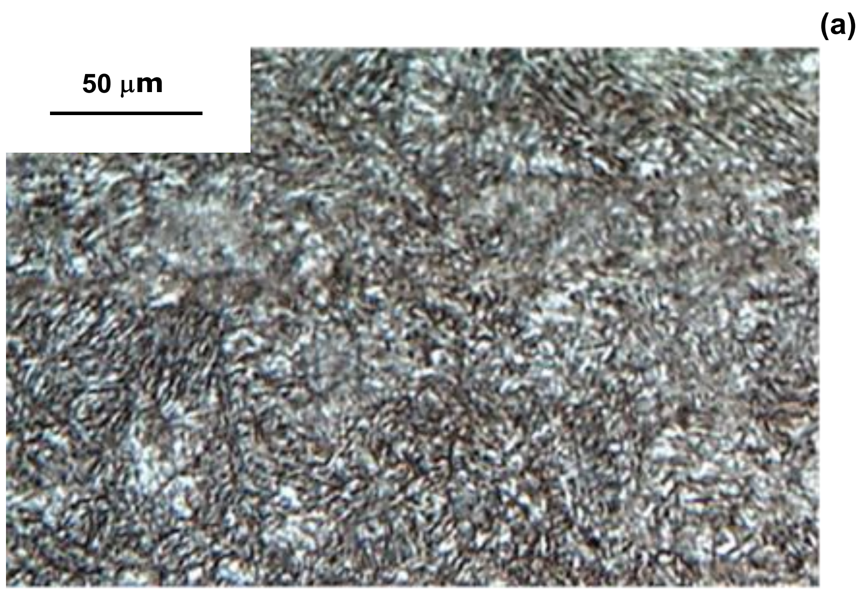


Figure 10. Carbon steel (a) and high strength structural steel with YS >700 MPa (b). Ferrite with small regions of pearlite. For the carbon steel, the mean grain size was 9 μm and for the high strength structural steel the mean grain size was 3 μm.



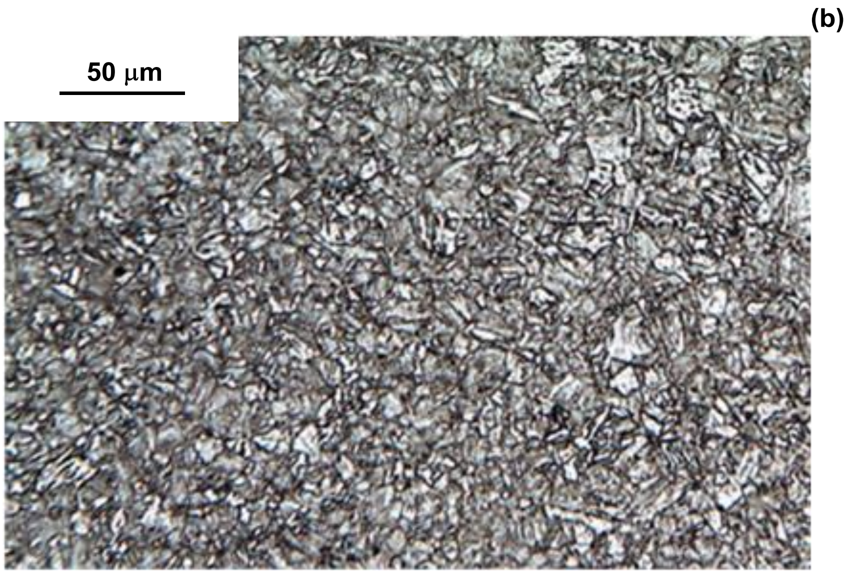


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Figure 11. Microstructures of the tool steel (a) and wear resistant steel (b). Tempered martensite with fine carbides.

Chromium carbide plating is a technique used when very high wear resistance is required. Figure 12 shows chromium carbide plating over a carbon steel base. The as-cast chromium carbides were deposited on the carbon steel and solidified growing from the base metal, Figure 12. These carbides guarantee the high wear resistance of the material. This chromium-plated material was substituted with a standard wear resistant steel in order to reduce the cost of this component, motivated by the fact that excessive wear was not a factor that limited the bucket service life.

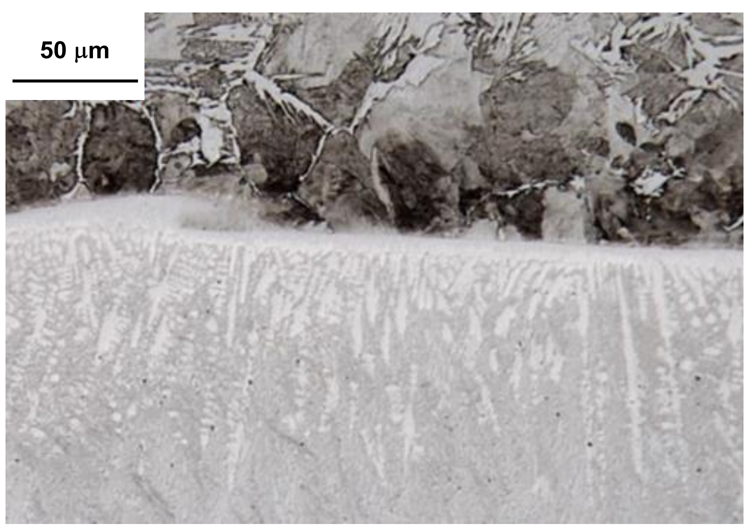
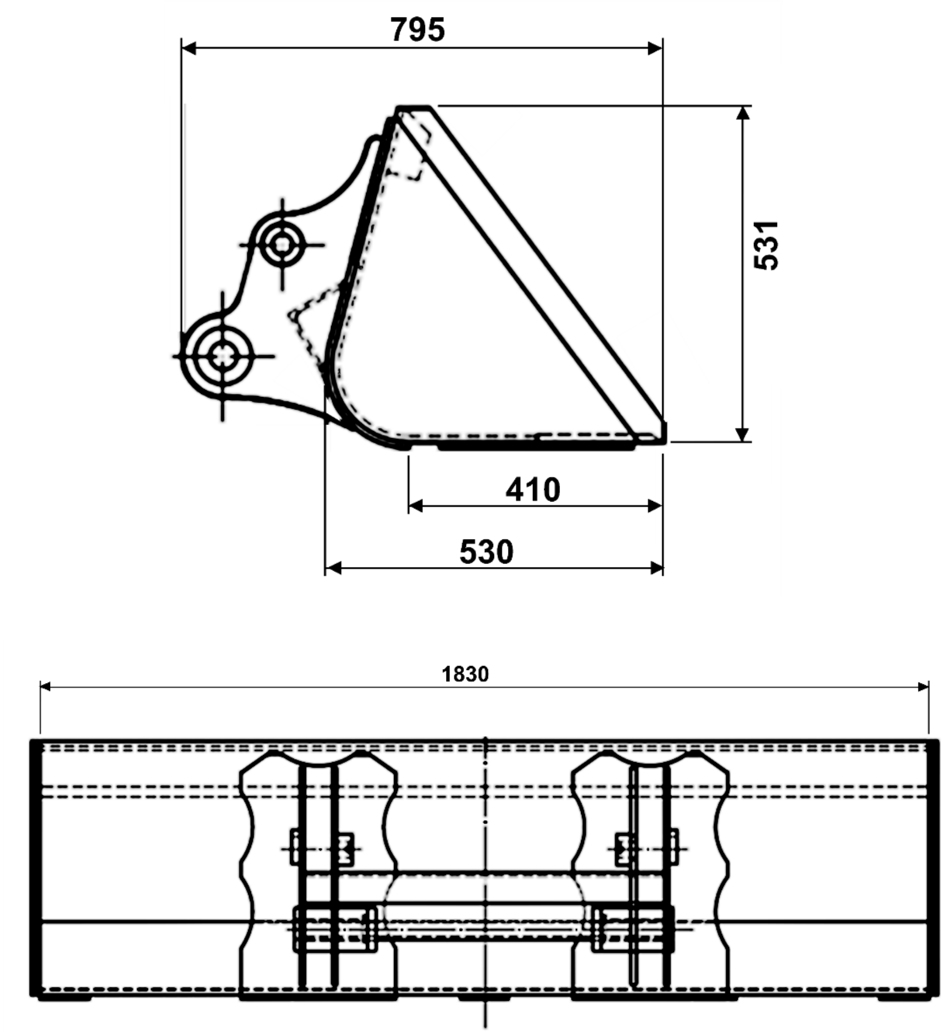


Figure 12. Microstructure of chromium carbide plated material. Upper section is the carbon steel with pearlite and ferrite at the grain boundaries. Bottom section is the chromium carbide plate, as-cast microstructure.

Results

<u>Stripped FeNb Ingot Loader Bucket</u>

The new bucket design is presented in Figures 13 and 14. The 15.9 mm strip of carbon steel was substituted with a 9.5 mm tool steel. This was the modification that was mainly responsible for reducing the weight by 25%, from 364 kg in the original model to 274 kg in the new design. Bucket load volume increased by 21%, from 0.24 m^3 to 0.29 m^3.



Weight = 274 kg and volume = 0.29 m^3

Figure 13. Main dimensions (mm) of the new bucket design.

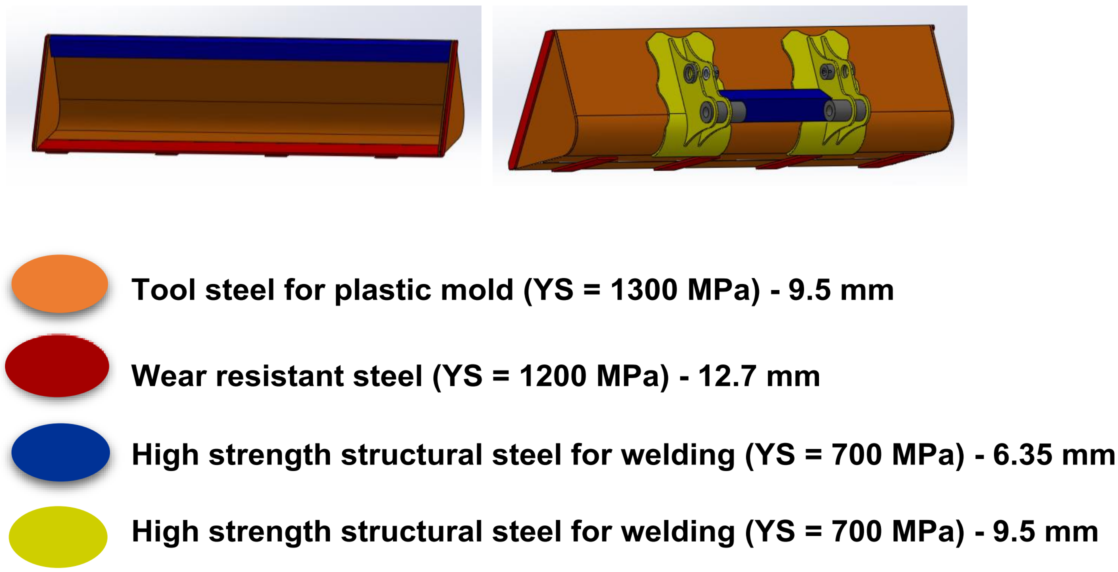


Figure 14. Steels used in the stripped FeNb ingot loader bucket.

To date, the new bucket has been working for 1,650 hours problem-free, which represents a 190% increase in service life over the best ever result for the original model, and a 415% increase over the original average life, Figure 15. The carbon steel parts that were susceptible to cracking in the original design were substituted with the tool steel and the cracks that normally appeared after 200 hours are absent in the new bucket. The tool steel worked well at the high temperatures involved when collecting hot FeNb and no deformation occurred in service, Figure 15. Figures 16 and 17 show the wear surface of the bottom strip at the front of the bucket, the part that has direct contact with FeNb on the floor. Scratches and adhesions of FeNb are visible, and there is some corrosion, but the resulting wear does not limit the bucket life cycle.

The initial higher investment for the new bucket containing high strength steel achieved payback after 800 working hours. The cost per working hour is as follows:

- Carbon steel based design – US$4.70/working hour
- High strength/wear resistant design – US$2.30/working hour

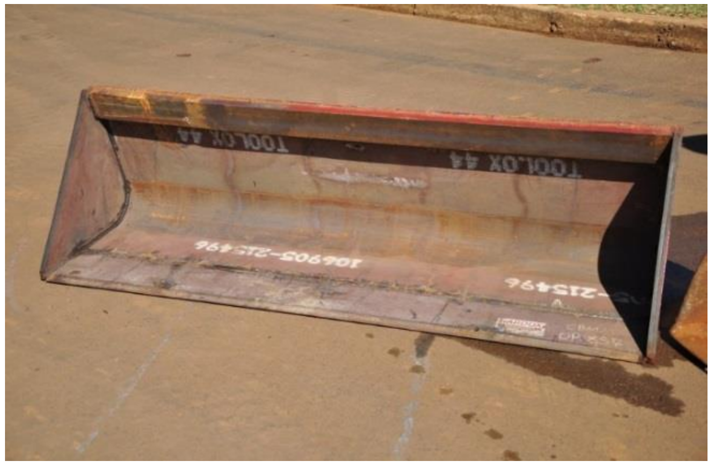


Figure 15. New bucket design after 1,650 hours of work time. No cracks and no deformation.

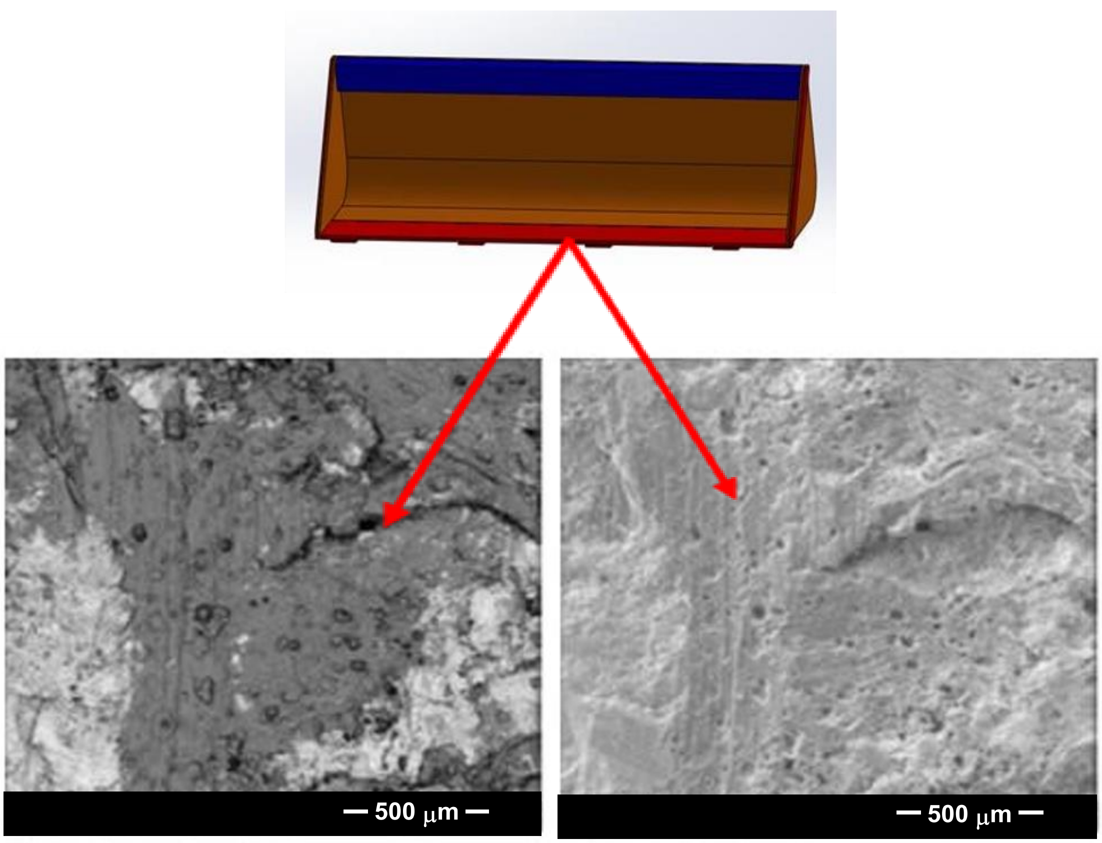


Figure 16. Wear surface of wear resistant steel with FeNb adhesion, scratches and corrosion.

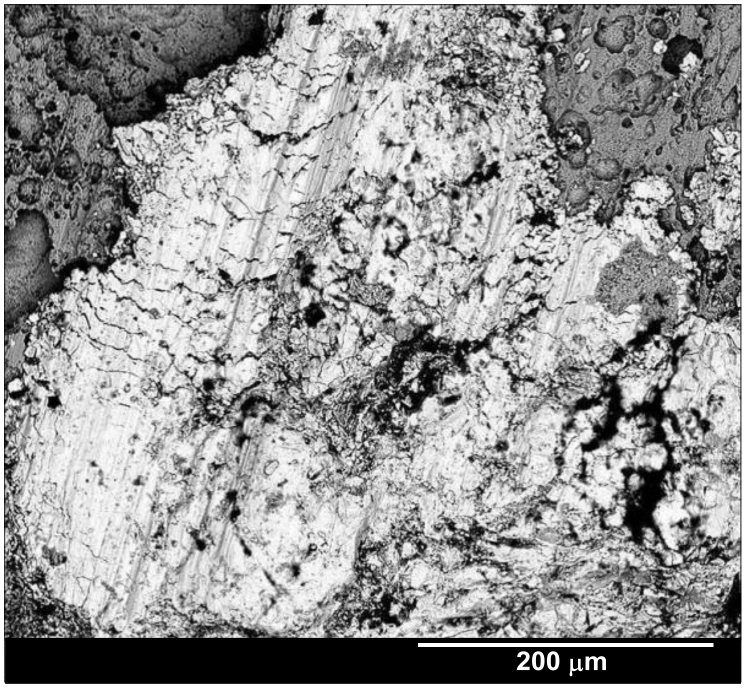


Figure 17. Surface of wear resistant steel.

Niobium Ore Loader Bucket

The new bucket has the same dimensions as the original, Figure 8. There was a 14% reduction in weight, from 3,508 kg to 3,013 kg due to reductions in thicknesses of the materials, Figure 18.

The 12.7 mm strip of chromium carbide plate was replaced by a 9.5 mm wear resistant steel, which was primarily responsible for the weight reduction. There were no cracks and no wear in the bucket after 11,000 service hours, showing that the higher strength steels have better fatigue resistance and that the chromium carbide plate was not necessary for the type of ore transported by the loader.

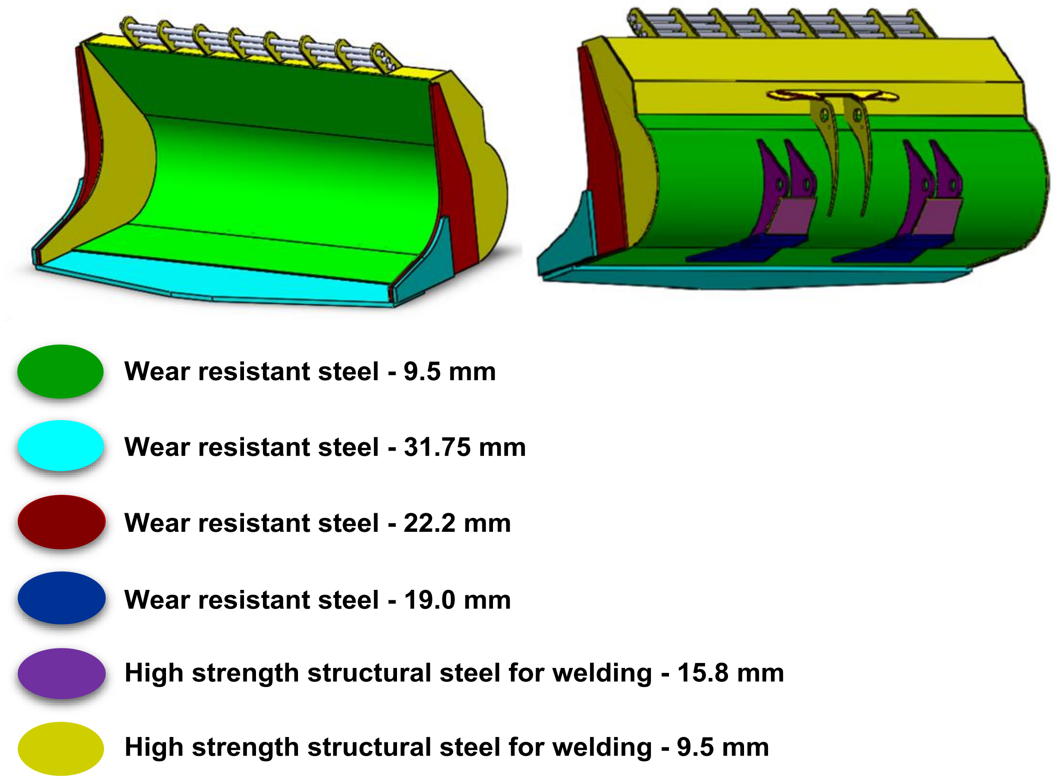


Figure 18. High strength and wear resistant steel used in the new niobium ore loader bucket.

The payload capacity increased by 4.7% while maintaining the maximum load allowed by the manufacturer specifications. With the 495 kg reduction in the bucket weight, it was possible to increase payload from 10,370 kg to 10,865 kg. Given the impossibility of working at the maximum allowed limit, this increase in payload made it possible to fill a 42-tonne capacity mine truck with four wheel loader buckets to 97% nominal capacity. The original design bucket required more than four buckets to fill the truck.

The cost of the original bucket was US$20,606. For the new design, since the plates treated with chromium carbide were replaced with a single wear resistant steel, the cost was reduced by 7.4% to US$19,090.

Conclusions

The application of high strength steels and a temperature resistant tool steel for the stripped FeNb ingot loader buckets made it possible to:

- Reduce bucket weight by 25%;
- Increase bucket load volume by 21%;
- Eliminate deformation caused by high temperatures;
- Eliminate structural cracks in the bucket, increasing service life by about 190% to date over the best recorded result for the existing design, and by over 415% compared to the average life;
- Reduce the cost of investment per working hour from US$4.70/h with the carbon steel design to US$2.30/h for the high strength steel design.

The following were achieved by redesign of the niobium ore loader bucket:

- Reduced bucket weight by 14%;
- Eliminated cracks even after 11,000 work hours, demonstrating that the higher strength steels have better fatigue resistance. There was no significant wear, indicating that the chromium carbide plate was not necessary for the type of ore being transported by the loader bucket;
- Increased payload capacity by 4.7% while maintaining the maximum allowable load as per the manufacturer's specifications. With this, four bucket loads were sufficient to fill the 42-tonne mine truck, allowing this process to be more productive;
- Reduced investment cost by over 7%.

References

1. A. Streisselberger, V. Schwinn and R. Hubo, "Microalloyed Structural Plate Rolling Heat Treatment and Applications," *Proceedings of the International Conference Niobium 2001*, Orlando, USA, 2001.

2. B. Donnay and H. Grober, "Niobium in High Strength Weldable Beams and Other Structures," *Proceedings of the International Conference Niobium 2001*, Orlando, USA, 2001.

3. L.M. Silvestre et. al., "High Strength Steel as a Solution for the Lean Design of Industrial Buildings," *Proceedings of the Value-Added Niobium Microalloyed Construction Steel Symposium*, Singapore, 2012.

4. K. Olsson et al., "Niobium Microalloyed Sheet Steels for Automotive Applications," *Microalloyed High Strength Steels for Reduced Weight and Improved Crash Performance in Automotive Applications* (TMS - The Minerals, Metals & Materials Society), 2006.

5. H.L. Rosa et al., “Increasing Transportation Efficiency by Using High Strength Niobium Microalloyed Steel for Truck Dumpers” (Paper presented at the International Seminar of Application of High Strength Steels in the Lightweight Design of Commercial Vehicles, São Paulo, 2013.)

6. K. Hulka, A. Kern and U. Schriever, “Application of Niobium in Quenched and Tempered High-Strength Steels,” *Materials Science Forum*, 500-501 (2005), 519-526.

7. N. Ishikawa et al., “High-Performance Abrasion-Resistant Steel Plates with Excellent Low-Temperature Toughness,” *Proceedings of the 2011 International Symposium on the Recent Developments in Plate Steels*, Winter Park Mountain Lodge, Winter Park, Colorado, 19-22 June, 2011, 81-92.

8. SSAB Brochure:
http://www.ssab.com/Global/Plate/Brochures/en/041_SSAB_plate_general_product_information_UK.pdf