OPTIMIZATION OF HIGH STRENGTH LOW ALLOY STEEL TO ACHIEVE REQUIRED OEM WEAR AND TENSILE PROPERTIES

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Abstract

The aim of this research was to study the effect of Nickel additions to high strength steel alloys and to obtain an optimal chemical composition that does not compromise the tensile strength and wear resistance properties provided by the OEM (Original equipment manufacturer) with cost saving to the manufacturing local foundry. The nickel content was added in composition from 0.5 wt% to 3.5 wt% to the molten metal. The test bar was then cut from the keel block and sectioned for laboratory analysis for determining tensile strength properties (ultimate tensile strength. yield strength and % elongation and wear resistance.

The results obtained shows that there is significant increase in tensile strength and wear resistance and slight decrease in toughness with increase in nickel additions. The best optimal chemical composition was observed to be 2.0 % nickel alloy for optimal cost to fulfil the OEM mechanical and wear properties for the high strength steel used for mining grounding application, so this meant a 22.7 % cost saving when compared to the current chemical composition used in the foundry.

Keywords: High strength Low alloy Steel, Nickel, OEM, Mechanical properties

1. INTRODUCTION

The foundry industry in South Africa reduced from 450 foundries in the 1980s to 170 foundries in 2014, the industry shrank further from 167 foundries in 2018 to 123 in 2020 was reported by CSIR [1]. There has been a 50% reduction in the number of foundries in South Africa between 2003 and 2020, this translates to an average annual reduction of about 3 %, meaning that on average about 8 foundries closed each year since 2003 [2].

Maintaining the status quo within the South African foundry industry will see the industry perish within 20 years or even less due to increase in production cost, it is for this reason that a technological intervention and less expensive production method and optimization of alloy used is warranted to keep the industry afloat [1].

2. LITERATURE REVIEW

2.1. High Strength low alloy Steels

High-strength low alloy steels (HSLAS) have similar composition as plain carbon steels; however, they are up to twice as strong, and their greater load-bearing capacity allows engineering use in lighter sections [3]. Their high strength is derived from a combination of grain refinement; precipitation strengthening due to minor additions of vanadium, niobium, or nickel; and modifications of manufacturing processes such as controlled rolling and controlled cooling of otherwise essentially plain carbon steel [4].

High-strength steels are used to reduce section sizes for a given design load which allows weight savings, reductions in section size may also be beneficial in obtaining the desired strength level during the production of structural steel, whether steels are furnished in the as hot rolled or heat-treated condition the strength levels tend to decrease as section size increases [5].

There is exhaustive research ongoing on the application of various grades of high strength steels; steel dictated the global market in term of revenue share, affordability and excellent properties of new steel grades including advanced/ultra-high strength steel are likely to positively affect its utilization in the mining sector over the forthcoming years [5] [6].

High-performance steels with improved properties are required for a wide range of applications including automotive, construction and energy sectors. These steels are increasingly produced as thermomechanical controlled processed (TMCP) grades where the microstructure is tailored to obtain a steel with the desired mechanical properties without any additional normalization treatments [7].

2.2. High Strength steel Application

Excavators are frequently used in the construction and mining sectors; they are the digger machines normally used for dredging materials in mine, digging, levelling the ground, etc. [8]. One of the components of excavator that is frequently replaced is bucket teeth [9].

Bucket contains protruding teeth on its edge, In the operation of excavator teeth have direct contact to ground or rocks as a result the material used for digger teeth should contain high strength, high toughness, high power and high wear resistance [9]. The wear behavior of teeth is a very important service life determining factor therefore abrasive wear is the dominant failure mechanism of excavator teeth used as a digger in mining industry [8] [9].

High strength cast steels cover the tensile strength range of 1200 to 2070 MPa (175 to 300 ksi), Cast steels with these strength levels and with considerable toughness and weldability were originally developed for ordnance applications, these cast steels can be produced from any of the above medium-alloy compositions by heat treating with liquid-quenching techniques and low tempering temperatures [5].

2.3. Effect of Nickel on the Materials Characteristics

Increasing nickel content generally increased strength, although the effect of nickel on yield strength and ultimate tensile strength is highly dependent on the quench rate from the austenitizing temperature [10].

Nickel is an austenite stabilizer and widens the austenite region and contracts the ferrite region in steel. Nickel improves the resistance against the corrosion and oxidation at elevated temperatures it also improves the toughness and strength by refining the grain size [11]. It also prevents scale forming on the material surface. When used with chromium, it improves the hardness, ductility, fatigue resistance and critical cooling rate. Elemental nickel has a lesser diffusion coefficient compared to many elements and diffuses into iron more slowly [12] [11].

Ni is known as an element which contribute to improve the hardenability and heat resistance of steel, the effect of Ni addition on the low alloy steel provides some benefits. Ni does not form secondary phases; it remains in the solid solution strengthening mechanism in the ferrite matrix it distributes in the ferrite matrix uniformly [11] [13].

3. EXPERIMENTAL WORK

A control sample (OEM Alloy) with specifications as conforming to table 1 requirements was cast and evaluated for mechanical and metallurgical properties to ensure that the conditions are like that of samples or products produced by the local Foundry.

Table 1 Chemical compositions of High Strength Low Alloy Steel as Supplied to the Foundry

Elements	% C	% Si	% Mn	% P	% S	% Cr	% Mo	% Ni
Specification as supplied by Foundry	0.23 - 0.27	0.55 - 0.75	0.8 - 1.0	0.015 max	0.015 max	2.5 - 4	0.25 - 0.35	3 - 4

A melt consisting of chemical composition in **Table 1** was melted using the induction furnace first without nickel content (Alloy A) then content of 1 % (Alloy B), 2 % Ni (Alloy C) 2,5% Alloy D then 3 % (Alloy E) Ni additions to the melt and poured into different resin bonded sand mould (**Figure 1**) and an additional proportion of 0.5 % was added into the melt to make keep block of Alloy A to Alloy E.

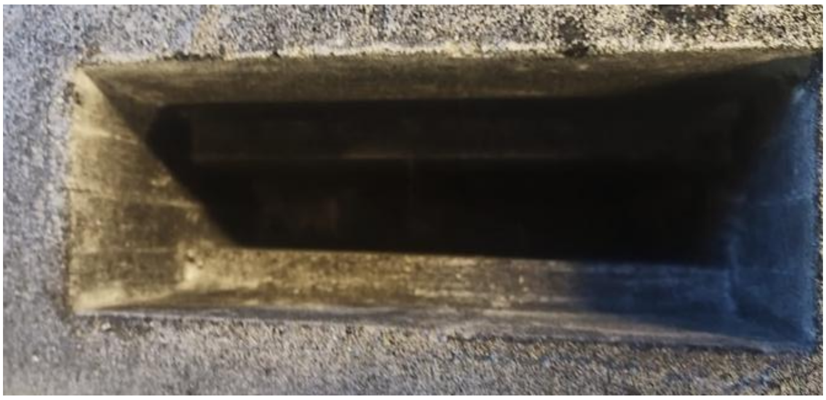

Figure 1 Resin bonded sand mould for casting

The melting and casting were closely monitored to reduce process variation and thus be able to assess effects of compositional differences. Each alloy produced was cut to obtain samples for chemical analysis, wear resistance, tensile specimens, and hardness testing.

The metallurgical investigation was conducted at the Department of Metallurgy, University of Johannesburg. Chemical analysis of the cast iron was carried out using a Q4 Tasman spectrometer, wear was conducted using Anton Paar Pin-on-Disk Tribometer wear Testing Setup, hardness testing conducted using King Brinell hardness tester and tensile testing conducted using 600 kN MTS universal tensile tester.

4. RESULTS AND DISCUSSION

4.1 Chemical Composition

Five samples cast from the same 50 kg melt of high strength low alloy steel chemical composition. The first sample (alloy) was cast without the addition of nickel (Alloy A), Alloy B was cast from the same melt, however, with an addition of 1 % of nickel. Alloy C was cast from the same melt with 2 % nickel addition and Alloy D was cast from the same melt with additions of nickel to obtain 2.5 % nickel and Alloy E was cast from the same melt with additions of nickel to obtain 3 % nickel content as shown on table 2, and control sample OEM alloy obtained from the local foundry.

4.2 Wear track width measurement

Figure 2 shows the measurements taken after wear testing were conducted on each alloy with high wear rate experienced by Alloy A that had very small quantity or traces on Nickel as compared to alloy B that contained about 1 % of Nickel. The high measurements were evident for Alloy E that contained the most Nickel content however there is slight comparable difference in wear rate from Alloy C to Alloy E.

The ratio of frictional force to applied load between two surfaces is quantified as the friction coefficient, it is a measure of the friction behavior of the material. From the results observed it is evidence that the friction coefficient was consistent between all the alloys. No correlation observed between Ni content in addition to the friction coefficient between the five alloys.

It is evidence from the results observed that there Increase in nickel content from alloy A with decrease in wear track measurements, with wear track width measurement for alloy A being the widest at 915.33 μm as compared to the wear track of alloy E with 3.0 % Ni. Increasing nickel amount in the material increases the hardness and the tensile strength of the material with decrease in track width measurements from alloy A.

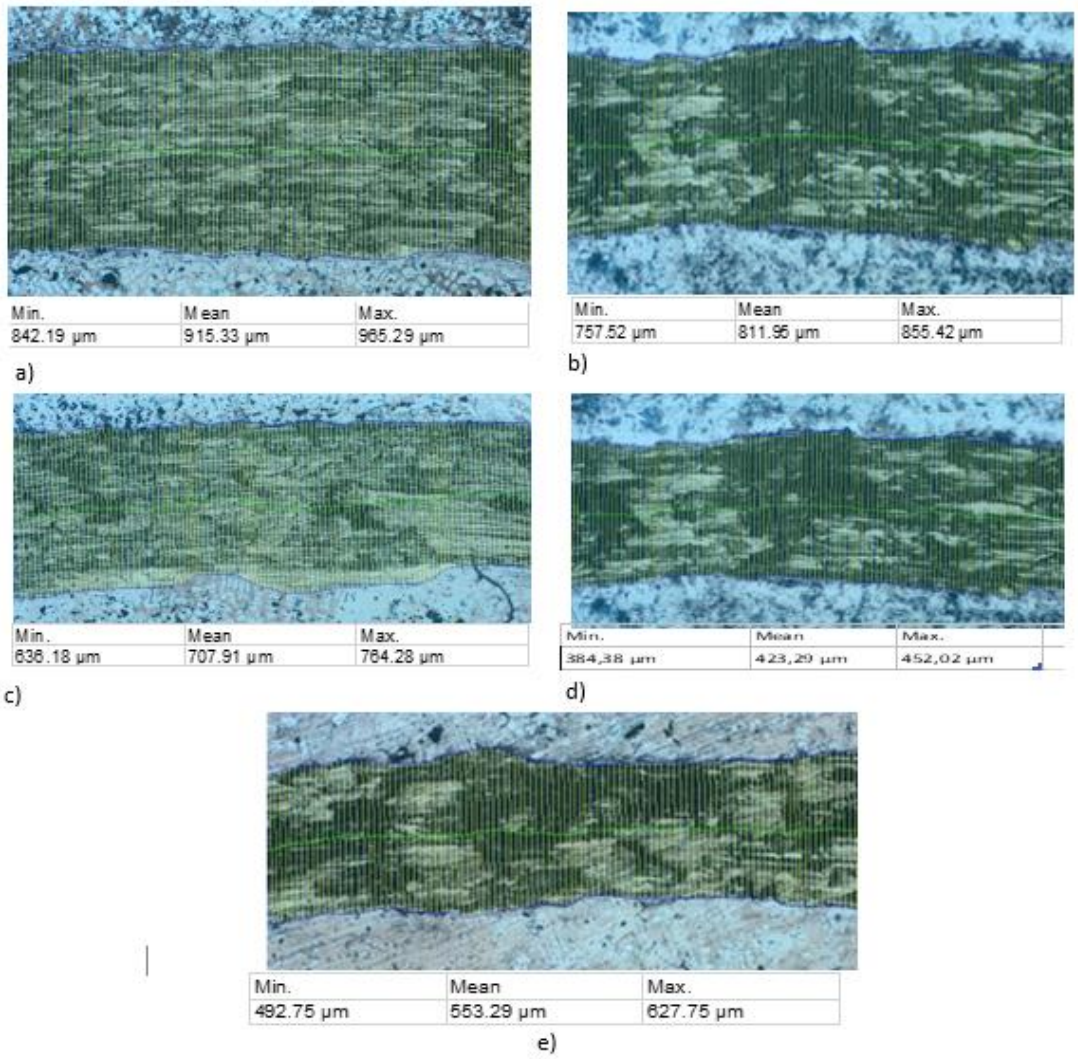

Figure 2 Showing wear Track measurements, a) for Alloy A. b) for Alloy B, c) for alloy C, d) for Alloy d and e) for Alloy E

Figure 3 shows the relationship between Volume loss and wear rate from Alloy A to Alloy E. Alloy A shows high Volume loss and high wear rate when compared to all other Alloys whereas Alloy D shows the least Volume loss, and the least wear rate followed by Alloy E.

The alloy that contained low amount of Nickel, alloy A contained the highest wear rate with volume loss of 2310 (mm^3/m) as compared to the alloy with alloy D that contained nickel of 2.5 wt% with volume loss of 1105 mm^3/m which also contained the best wear resistance when compared to the rest of the alloys. The alloy that contained 2 wt% nickel contained the wear rate that is comparable to the rest of the alloy 2.5 wt% alloy and however the alloy E, that contained the highest nickel content 3 wt% Nickel did not contain the best wear resistance and volume loss on the material as suggested by the previous studies by Tian [12].

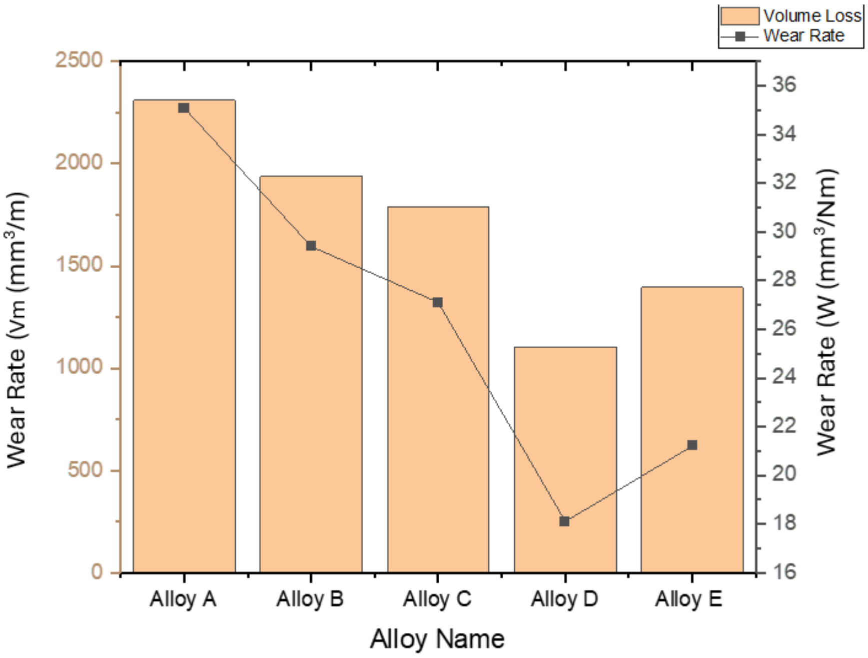

Figure 3 Relationship between Volume loss and wear rate

4.3 Tensile test

The tensile test results obtained from Alloy A to Alloy E conducted using standard test method ASTM E8/E8M. The results show a significant difference in the tensile parameters with increase in yield strength with increasing nickel content from Alloy A to Alloy E. The results observed for alloy C to alloy E are within the OEM alloy minimum requirements for 0.2 % yield strength and ultimate tensile strength, alloy A and B are outs observed minimum requirements of OEM specification. The Ultimate tensile strength increases significantly from Alloy A to Alloy E while there is noticeable decrease in percentage elongation and reduction in area from Alloy A to Alloy E.

5. CONCLUSION

Melt charge calculations were conducted successfully to give the variation of nickel content of the five alloys (samples) were performed and an increase in nickel content increased the Brinell hardness value of the alloys as well as the yield and ultimate tensile strength and wear resistance of the material. From the experiments Alloy C, D and E gave mechanical and chemical results that are within the OEM high strength steel alloy requirements, increasing nickel content led to an increase in wear resistance of the material from 1 % nickel and a slight improvement after 2 % nickel. Increase in nickel content to 2 % retains wear resistance of the material.

Below 2 % nickel content there is compromised in tensile strength. Impact toughness and metallographic appearance of the material, there is an overall saving of more than 22.75 % of cost of producing the High strength steel with 2 wt% of nickel as compared to producing above 3 % without compromising the Mechanical, Wear resistance and Metallurgical properties of the alloy. A total savings of R20 399.45 is obtained in every 5ton produced by using alloy C that contains 2 % Ni content. Increase in nickel content from zero to 2 % content shows an improvement of about 50 % in mechanical and wear resistance of the alloys.

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