ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
ISSN: 1584 - 2673

EFFECTS OF MICRO ALLOYING ON HARDNESS AND TOUGHNESS IN CAST STEELS

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ABSTRACT:
This paper presents the effects of micro alloying of vanadium and niobium elements into the low carbon cast steels on the microstructures as well as hardness and toughness properties. The addition of these microalloying elements in the base steel significantly improved the hardness to 16% and 31% in vanadium and niobium microalloyed cast steels respectively. On contrary the toughness was reduced to 28.5% and 32% in vanadium and niobium microalloyed cast steels respectively. Fine grains were obtained in microalloyed cast steels and coarse grains were found in unmicroalloyed cast steels. This paper discusses the grain size strengthening mechanism of metals and fractography analyses of broken impact specimens.
KEY WORDS: micro alloy**,** grain size strengthening, cast steel, microstructure, hardness, toughness

1. INTRODUCTION

The casting process has become the method of choice for producing complicated components. Among the materials used to produce castings, specifically steel plays a major role in the production of critical castings. The waste produced per ton of metal in the production of various metals [1] is shown in the Fig.1.

From the Fig1, it is evident that the solid waste generated in steel is the minimum compared with other metals. So it is better to use steel in various applications instead of other metals by improving the mechanical properties. The increase in strength properties in steel can be achieved either by increasing the carbon with manganese content in the steel. Subsequently, these additions make the steel brittle and poor weldabilty. Therefore, a technique is required to increase the strength properties of the steel without the decrease of other mechanical properties and weladability. The mechanical properties can be improved by the addition of vanadium, niobium, titanium, and zirconium into low/medium carbon steels at a micro level. In this paper, the grain size strengthening mechanism of metal is discussed in addition the experimental findings of the micro alloying elements vanadium, niobium on the hardness, toughness and microstructures of the cast steel is presented.

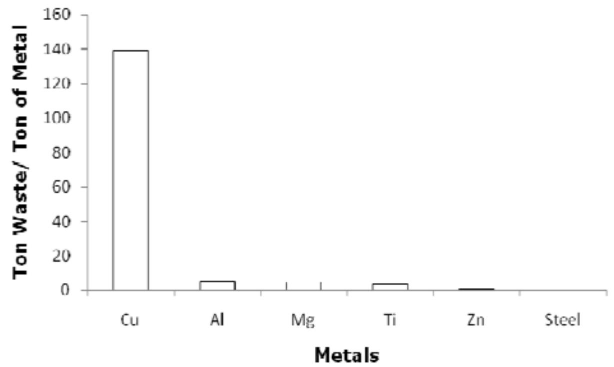

Figure1. Waste produced in metals

2. MICRO ALLOYING IN CAST STEELS

Generally the strength of the metals can be increased by alloying in the base metals. Specifically certain elements are added at minor level into the base metal to improve the properties. Micro alloying steels are basically low alloy steels having the addition of small proportions of elements like titanium, vanadium, niobium and zirconium, etc[2,3]. These elements are added alone (maximum 0.1%) or combinations of small proportion so that the total alloy addition is within 0.2% apart from C, Mn, Si, S and P.

Addition of alloying elements at a micro level influence the properties in various ways according to the type of elements, percentage addition and addition of alloying elements in combinations with each other into the base metal.

3. STRENGTHENING MECHANISMS OF METAL

Metals are weak due to the presence of dislocations. The strengthening mechanisms are used to increase the strength of metals. They are grain size strengthening, solid solution strengthening, precipitation strengthening, dislocation strengthening and transformation strengthening, etc. The stress required to move the dislocations is increased by adopting these mechanisms. The various strengthening mechanisms to the yield strength [3] are shown in Fig 2.

The major contribution to the yield strength comes from grain size strengthening and solid solution strengthening. The grain size strengthening mechanism is discussed in this paper.

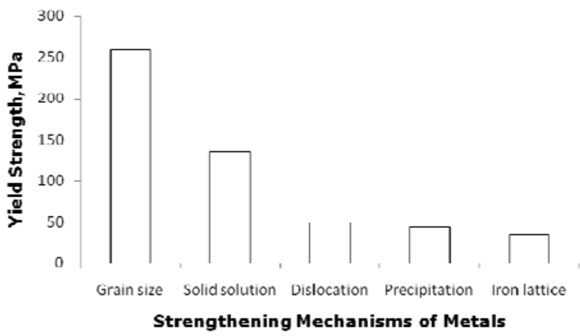

Figure2. Strengthening mechanisms of metals

3.1. GRAIN SIZE STRENGTHENING

Lower strength is obtained in steels in the cast condition than in the cold or hot worked state. Defects like cavities and cracks are present in the cast steels where as these are not in the cold or hot worked steels. In addition coarse primary grain structure is obtained in cast steels and refining is also difficult. However, the strength of the cast steel is increased by the formation of fine grained structure. The best method of refining the grain size is micro alloying of carbonitride forming elements such as vanadium, titanium, niobium and zirconium into the base steels. Dispersed carbonitrides are formed by the addition of these elements into the base steels. The effective grain refining effect has been achieved by dispersion hardening. The precipitation of vanadium, titanium, niobium and zirconium is taking place in low carbon, low alloy base steels due to the effect of dispersion hardening. The solubility of carbonitride forming elements determines the grain refinement. It is possible to decide the quantity of these micro alloying elements may dissolve in the austenite and formation of precipitates by determining the maximum solubility. It is found that the optimum addition of vanadium is 0.12%., niobium is 0.6%, and titanium is 0.04% respectively [4] for low carbon steel to get maximum strength. The strengthening effect is poor when the percentage addition of these micro alloying elements exceeds this limit.

The effective carbonitrides boundaries retard the austenite grain growth in heating. This effect of carbonitrides in micro alloyed cast steels makes the steel to obtain finer austenitic grains than the grains normally available in low alloyed cast steels. The smaller effective grain size is obtained due to these finer austenitic grains.

Precipitation of dispersed carbides or carbonitrides is taking place at the newly formed ferrite austenite grain boundaries in cooling during normalizing. These precipitate at the grain boundaries increase the strength of the cast steel.

Table1. Effect of grain size on properties

Property	Structure	
	Coarse Grained	Fine Grained
Yield strength Tensile strength Ductility Toughness Hardness Fatigue resistance Resilience Surface finish	Less	More
Creep resistance Corrosive resistance Machinability Retained austenite Corrosion resistance Hardenability Tendency of formation of quenched cracks	More	Less

The grain size number 1 – 12 is specified by ASTM as a standard. A grain size number below ASTM number 3 represents coarse grained steel and above ASTM number 6 represents fine grained steel. Steels having ASTM grain size number above 8 are called as ultra fine grained steels. The effect of grain size on properties is given in Table 1.

4. EXPERIMENTAL PROCEDURE

A medium frequency coreless induction furnace of 50 kgs with basic lining was used for melting. Initially mild steel scrap was melted and ferro manganese, ferro silicon were added to the base metal. The base metal composition has given in Table2 was achieved by the required addition of necessary alloys with the help of the vacuum spectrometer. The vanadium and niobium levels were maintained at 0.10% in steel 2 and steel 3 respectively. The unmicroalloyed and microalloyed heats were tapped at 1610^{0}C. The deoxidisers aluminium and calcium silicide were added in the ladle. The liquid metal was poured into standard Y block sand moulds.

Table 2. Chemical compositions of the experimental steels wt %

Experimental Steel	C	Mn	Si	S	P	Cr	Mo	V	Nb
Steel 1	0.23	1.20	0.42	0.03	0.02	0.13	0..02	0.00	0.00
Steel 2	0.23	1.20	0.42	0.03	0.02	0.13	0..02	0.10	0.00
Steel 3	0.23	1.20	0.42	0.03	0.02	0.13	0..02	0.00	0.10

The microstructures were obtained by an optical microscope. Hardness was measured by using a zwick hardness tester with an indentation load of 10kg. The impact energy was measured by charpy method using standard test pieces (55mm length, 10mm square with V notch 45^0, 2 mm deep with 0.25mm radius at a base notch). The metallographic examinations were done in an optical microscope and the fractured specimens of charpy the tests were analyzed in SEM.

5. EXPERIMENTAL RESULTS AND DISCUSSION

5.1. MICROSTRUCTURES

The microstructures of unmicroalloyed, vanadium, niobium microalloyed cast steels are shown in the Fig.3. The major influence of micro alloying on grain refinement is evident by comparing the microstructures of the unmicroalloyed and microalloyed cast steels. The carbides of microallloying elements added were present as bright patches in the ferrite matrix. Grain size of austenite existed prior to its transformation to ferrite, cementite or martensite.

The grain coarsening is observed in the unmicro alloyed base as cast steel 1. Grain refining effect was found in the micro alloyed as cast steel 2 and steel 3 respectively due to the addition of micro alloying elements. The grain size was refined in steel 2 and steel 3. All the micro alloyed steels have less grain coarsening than the base steel 1.

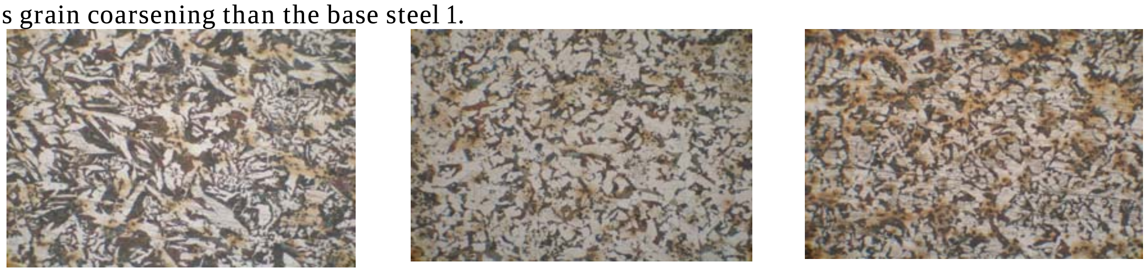

Figure3. Optical microstructures (100x) of (a) unmicroalloyed base steel1, (b) V microalloyed steel2 (c) Nb microalloyed steel3

Grain size of ferrite is produced by transformation. In the low carbon steel amount of ferrite is maximum and hence properties are strongly influenced by ferritic grain size and not depend on austenitic grain size [5-9]. However fine austenitic grain size produces fine ferritic grain size and hence finer the austenite grain sizes better the mechanical properties.

5.2. MECHANICAL PROPERTIES OF MICRO ALLOYED CAST STEELS

The mechanical properties tested in the un micro alloyed and micro alloyed experimental steels were analyzed. The results of the hardness and toughness properties obtained in the experimental steels are shown in Fig.4 and Fig.5 respectively.

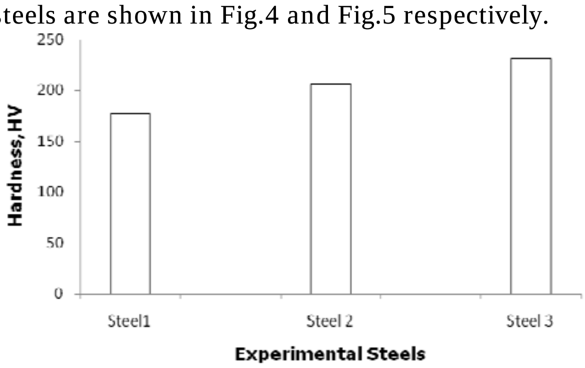

Figure4. Hardness of experimental steels

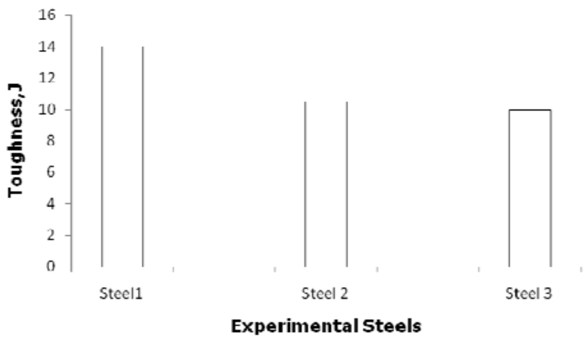

Figure 5. Toughness of experimental steels

The hardness due to micro alloying is increased to 16% in vanadium micro alloyed steel 2 and 31 % in niobium microalloyed steel 3 respectively in comparison to the unmicroalloyed base steel 1. The highest hardness was obtained in experimental steel 3 was as high as 232HV. The toughness due to micro alloying is decreased by 28.5% in vanadium micro alloyed steel 2 and 32% in niobium microalloyed steel 3 respectively in comparison to the unmicroalloyed base steel 1.

5.3. FRACTOGRAPHY ANALYSIS

Fracture in engineering alloys is classified into two types viz. transgranular or an intergranular. If the fracture occurs through the grains, then the fracture is known as transgranular whereas if the fracture occurs along the grain boundaries, the fracture is known as intergranular fracture. Apart from the fracture paths, the four modes of fracture are dimple rupture, cleavage, fatigue and decohesive rupture. The strain in the material increases when the microvoids grow as well as forms a continuous fracture surface and finally results as dimple rupture.[10] In this fracture lot of cup like depressions are formed due to the result of microvoid coalescence. The depression looks like cup are known as dimples and this fracture mode is called as dimple rupture. The fractography of broken impact specimens of unmicroalloyed and microalloyed as cast steels is shown in the Fig.6

Large and small dimples on the facture surface was observed in the fractured surface of vanadium micro alloyed experimental cast steel 2. large and small sulphide inclusions are also seen in the fractured surfaces which act as void nucleating sites.

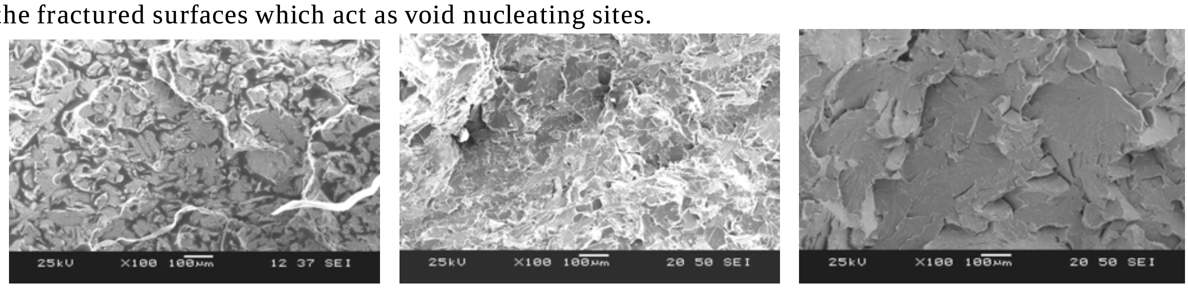

Figure 6. Fractographs (100x) of (a) unmicroalloyed base steel1, (b) V microalloyed steel 2 (c) Nb microalloyed steel3

Quasi cleavage fracture was noticed in unmicroalloyed cast steel 1 and microalloyed steel 2. The fractured surface shows the characteristics of both cleavage and plastic deformation. Generally quasi cleavage fracture was observed in precipitation hardeneable, quenched and temper hardenable steels. Brittle fracture was observed in experimental steels 2 and 3.

6. CONCLUSIONS

This paper presents and discusses the grain size strengthening of metals, which are major among the other strengthening mechanisms of metals.

Grain refining in micro alloyed cast steel was observed due to micro alloy additions of vanadium up to 0.10% and niobium up to 0.10% into the base steels. Fine grains were found in microalloyed cast steels and coarse grains were obtained in unmicroalloyed cast steels.

An increase of hardness to 16% and 31 % was found in vanadium and niobium microalloyed as cast steels respectively when compared with unmicroalloyed cast steels. The hardness obtained was as high as 232HV.

A decrease of toughness to 28.5% and 32% was found in vanadium and niobium microalloyed as cast steels respectively when compared with unmicroalloyed cast steels.

Generally, the hardness was increased and toughness was reduced after micro alloying in all the micro alloyed as cast steels.

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