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Review of Titanium Related Inclusions in Casting of Steel

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Abstract

The general area of understanding is inclusions in steel both metallic and nonmetallic in nature. This work has also used the concepts of inclusions in steel in general other than Ti however mainly the research works done on precipitation, solute segregation, grain developments and equilibrium aspects of important inclusions like Ti in steel have been probed. Interaction of inclusions with slag oxides has also been incorporated. Interdependence of elements common in-between many inclusions has been marked. TiN, TixOy and MnS inclusions have been very outstanding in the confines of present research. Ratios and effective concentration have been highlighted in certain cases around the topic. Type of steels, compositions of the constituent elements and temperature correlation has been spotted in certain environments. A suggestive relation with the steel properties has also been inferred. Hardness, corrosion behaviour and strength stand out to be the parameters of vital importance when considering Ti inclusions in the form of either TiN or TixOy. Certain inclusions like MnS seem to nucleate on TiN inclusions and there is a correlation evident certainly in case of complex alloys.

Keywords: Titanium oxides, Nonmetallic inclusions, Titanium nitrides, Titanium carbonitrides, Manganese sulphide

1. Introduction

Since kinetics and thermodynamic aspects of metallic and non metallic inclusions is our research area with focus on titanium in steel and its pros and cons; the approach used in the present work is foremost review of research done on the inclusions in steel. The stated phenomenon is predominantly related to casting of steel. Inclusions cannot be avoided altogether so the strategy utilized by most researchers is to optimize them to the best of requirements of the type of steel being cast.[1] In different environments of casting methods in separate set of conditions according to the applications, different types and amounts of inclusions in terms of elements and their percentages, can be observed and investigated via typical techniques of foundry. All have some effect on certain properties of various types of steel.[2] For instance, if we confine down to our specific problem area which is Ti in Fe-C solvent, we can infer from the work done on characterization, modelling and prediction of effect on properties that it is this research is worthwhile.

To pin point, Ti seems to have considerable effect on medium carbon steel in terms of hardness. Also with Ti inclusions some steels have shown better corrosion resistance. And it goes without saying that Ti being a very strong element of the periodic table when merged with Fe-C solvents which are commonly known as steel, can have a good effect on strength of the alloy too. These are the basic effects of such an inclusion in steel. This inclusion is not unitary in nature; for instance, we find Ti in the form of TiN and Ti_xO_y in the steels particularly during casting processes. One needs to keep in mind that some inclusions in certain environments go hand in hand with TiN and Ti_xO_y; for instance, MnS is seen to be evident in solute segregation studies. Sometimes one inclusions is nucleated on another and their components when in common affect the precipitation of the other. [3]

Characterization techniques like optical microscopy (OM), energy dispersive spectroscopy (EDS) and scanning electron microscopy

(SEM) stand out alongside the modelling done on simulation tools like Factsage and Thermocalc.[4] The type and composition of steel, processing time and temperature stand out to be vital parameters in such studies. Phases and grains can be predicted, based on simulation models and correlation with important properties can be established therefore. [5]
The findings have been compiled topic-wise with brief description in the context and categorically stated in the main body of this work. In short, an attempt has been made to mark the importance of controlled amount of inclusions in steel casting, in order for researchers to have a qualitative summary related to the effect of general as well as Ti specific inclusions. TixOy, TiN, TiC and TiCN stand significant when we try and relate properties like hardness, abrasion resistance, corrosion resistance and strength at this juncture of knowledge.

2. Overview of existing methodologies

A cursory approach is adopted to develop insight in to metal processing rather casting of steel, keeping in view the kinetics and thermodynamics of precipitation and solute segregation. More than quite a few solid studies have been probed and evaluated for their inferences in steel and their removal have been highlighted for condensed inferences to correlate the findings and try to mark the important areas of input of modern research. Starting from the theoretical expectation of inclusion behaviour in steel, to physical chemistry, to thermodynamic models have been studied, in order to draw important conclusions relating to the general phenomena of inclusions. Role of elements like titanium, their interaction with elements like oxygen and nitrogen has been evaluated, not undermining the possibility of coexistence with other significant solutes which tend to form and distribute during the very phenomenon of precipitation. [6] The inferences drawn are subject to the definition of the case; for example, temperature range, solute concentration, coexistence of solutes, geometry and fluid flows and also the type of process under consideration and some basic assumptions before the execution of modelling by the referred researchers. Other casting defects not directly regarding the inclusions are not the emphasis of this study. Nonmetallic inclusions 'NMIs' have been the major focus in this qualitative study.
To confine, extensive literature review has been carried out to understand metallurgical aspects of casting of steel especially in the very contest of inclusions. Important findings of the theoretical knowledge and the industrial works have been put together for better understanding of the phenomenon. Important inferences of analytical studies have been gathered alongside the conclusions of the models of currently available tools like FACT, Factsage and Thermocalc, and have been noted down. Overall, an attempt has been made to converge the findings on inclusion control in steel making in a qualitative manner.
Certain relevant cases have been studied on general as well as Ti specific inclusions during steel casting. There are multiple types of steels and types of casting processes deployed to make them. The concept here is to collect the main findings of research works done and condense them in a descriptive manner. The objective is to use this knowledge in the uplifting of the process for enhanced output in casting in general. The inferences have been briefly described case-wise to state them in the very context.

2.1. Aspects of general inclusions in steel

NMIs are unavoidable in the liquid steel but optimization is under way. According to basic thumb rule, if the slag is looked after well, the quality and properties of metal are retained and consequently improved. In continuous casting the operations of transfer must be deployed, self-open ladles with refractory shrouds which are non-reactive and optimized, protection related to argon gas, sealing to not allow reoxidation, nozzle clogging and the entrapment of slag.[7] In fluid flows in casting operations the very properties of steel making vessels, furnaces, ladles, and casting moulds are heavily affected by fluid flows of the process. Thermodynamics of alloy steel casting imply that especially oxygen content and the metal composition at the initiation are the major factors in metal modification and consumption of high value components.[8] Macrosegregation in the continuous casting of steel indicates that inside the mushy zone on space and time, the solid phase part distributions and impurities' temperatures are unstable and carry wave type properties. Equilibrium in the precipitation of microalloyed steel suggests that when some alloying elements are used up, the equilibrium amount of other precipitates may decrease, and the very formation may be delayed because of the effect of second precipitated phase mutual solubility formation.[9] Elementary process in molten oxide slag reduction suggests that geometry of elementary reaction is important in the reliable process modelling of slag reduction. Probable position of carbon grain is at the interface of gas/slag. The reaction between slag and solid carbon is obvious and very much affects the rate of the process.[10]
Following table is a reasonable qualitative compilation of the findings on general inclusions which in the present case study are all other considerable trace elements except the Ti compounds in order to establish a reference point, for instance Al, Mg, V, Zr in general and Mn and Si in relation with Ti.

Table 1.
Inferences on general inclusions other than Ti based traces

Method	Case	Results
Study based on theoretical computations	Control of NMIs in liquid steel	First up, slag is to be taken care of if metal quality is required.
Analytical calculation study	Macrosegregation in solidifying continuous casting steel billet	Inside the mushy zone, solid phase part distributions and the impurities' temperatures are unstable and carry wave type properties.[11]

Computational model study	Model of precipitation in microalloyed steel	In case of some alloying elements being shared the equilibrium amount of second precipitated phase may be decreased.
Thermodynamic analysis study	Analysis of elementary process in molten steel oxide reduction	Geometry of elementary reaction is important in the reliable process modelling of slag.
Study based on industrial quantifications	Physical chemistry of rare earth elements and group IVa	Al, group IVa and rare earth elements due to their strong affinity for oxygen can be used as strong deoxidizers of liquid steel, demand for elements like titanium, vanadium, zirconium etc has increased with modernization in industry.[12]
Metallurgical analysis study	Composition of oxide inclusions in production of microalloyed steel	Calculations require microalloyed steel production with low solute concentrations, results show the obvious role of Ti in the inclusions's formation.[13]
Thermodynamic analysis study	Model of deoxidation equilibria in steel	A study data indicate that the solutes of metal in the liquid iron also forms MN and MS with dissolved N and S where M[Al,Cr,Ca,Mg] is a multi-element deoxidizing agent.[14]
Thermodynamic analysis study	Thermodynamics of N, Al and AlN formation in liquid iron	With changing N partial pressures and using metal nitride gas equilibration technique, when the amount of Al was increased, the solubility of N in liquid Fe decreased.[15]
Experimental study	Inclusions in steel with Ca treatment	Alumina before treatment were rather converted to calcium aluminates which had small quantities of MgO and SiO2.[16]

2.1.1. Precipitation and coarsening of Ti inclusions in micro alloyed steel

The study done via the coupling models indicates that the mushy zone goes through coexisting phase zones whilst the process of solidification. N and Ti predicted as solute concentration by variable parameters are quite different than those predicted by fixed parameters. If N content is too low, there is no TiN precipitate in molten steel. Ti content has effect on both the size of TiN inclusion and shortening the temperature of precipitation. [17]

2.1.2. Assessment of MnS inclusions in heavy rail steel

Thermodynamic assessment of the stated U75V steel in terms of precipitation has revealed interesting facts. Segregation ratio of Mn is Lower than that of S during solidification, at solid fraction well above 0.9, MnS inclusion will precipitate. [18] Increase of initial concentration of Mn will mark the time of precipitation much easily. Compounds of Ti_xO_y will be participating later than TiS and earlier than MnS. For instance if we make a sequence it will look like $Ti_3O_5 \rightarrow Ti_2O_3 \rightarrow TiO_2 \rightarrow TiO$.

2.1.3. Growth of Ti inclusion in tyre chord steel

In the refining process; EDS and SEM show that main inclusions are rather in the form of TiO_x which tend to coexist with some other inclusions. If microsegregation of solute is not taken into account, TiO_2 & Ti_2O_3 particles precipitate later than Ti_3O_5 particles; with consideration of the microsegregation Ti & N follow and the degree of segregation of oxygen remains the strongest. Rate of cooling affects Ti inclusion particle size in precipitation. Higher cooling rate makes a smaller size. [19]

2.1.4. Identification of TiN inclusions formed while steel solidification

In Medium carbon steel with different Ti & N contents, during the characterization of precipitates, it is observed that the oxides and sulphides are normally detected in these steels, also in the final product Ti rich precipitates are seen varying in size. Density of particles seemed similar to that in as-cast steel. [20] Amount of Ti particles was seen to be too low in the liquid region. It indicates clearly that precipitation matures with solidification.

2.1.5. Analysis of MnS-TiN inclusions in low sulphur steels

High amount of inclusions can be collected, which actually allows collecting MnS inclusions in steel which are quite low in sulphur. This collection is carried out in a convenient way. Theoretical and experimental study indicates that TiN precipitates at 1598K in very grain boundaries of austinite . [21] The Mn and S activity level in the vicinity of TiN increases with depleting N and Ti. MnS inclusions somewhat nucleate on TiN inclusions heterogeneously on more lowering of temperature to 1570K. [21]

2.1.6. Influence of N and Ti addition to NiCrMoV Steel

The stated steel can be modified, one way is by adding Ti, it results in increase of hardness in a steel which is tempered in the referred way. Usually addition such as N and Ti are not a good recommendation for the steels of the stated type. Explanation is found in the results of thermocalc; the hardness changes due to an altered chemical composition, or in other words because of change in tempering temperature. The study shows that Ti addition does two things; one, that it increases the activity level of molebdenum, and two, that it decreases the activity level of chromium. [22] Also when Ti is present, the formation of cementite phase is delayed at high temperatures.

2.1.7. Precipitation of TiN in low alloyed steel during cooling

As the solidification process ends, the segregation of Ti takes place in interdendritic and intergranular zones. Along the lines of segregation, in the upper austenite, nucleation of TiN seems to occur. The precipitation of TiN induced by deformation in the low alloyed steel which contains 0.025-0.040% Ti and about 0.01% N actually occurs after or during solidification below or around 1100^{O}C. [23] Growth of the particles is marked by the extent of diffusion of Ti. Lower temperature implies larger distances between the nuclei, and for further precipitation, the more is the time needed.

2.1.8. Ti addition on steel with medium carbon content

Ti addition has good effect on refinement of grain and so an effect on hardness, impact toughness and to an appreciable extent on some mechanical properties in general. As the final forging temperature decreases from 1050^{O}C to 900^{O}C passing the mark of 925^{O}C, the refinement of grain increases.[24] As the Ti content increases from 0.0015% - 0.25%, the ferrite to pearlite proportion enhances, the finish forging temperature has negative but little effect on the ratio of ferrite to pearlite. [24]

2.1.9. Ferritic stainless steel and the effect of Ti addition on it

The addition to Fe17Cr of Ti, which is ferritic precipitate after solidification. Also, it is the center of the ingot where TiN precipitation takes place. Two types of TiN precipitates in the stated steel exist, TiN precipitate and the TiN precipitate heterogeneous oxide core, consequently boosting corrosion resistance. [25]

2.1.10. Ti stabilized 17Cr Austinitic steels and the formation of inclusions

With regard to the formation mechanism of various inclusions; thermodynamics analysis implies that pure particles of TiN are formed in the liquid phase, which is due to the high concentrations of N & Ti solutes in the molten steel. [26] Also, according to SEM and EDX, the pre-existing oxides give heterogeneous nuclei for TiN precipitation. [31]

2.1.11. Solid solution behaviour of Ti inclusions

Ti inclusions solid solution behaviour in tyre chord steel is studied during the heating process, In theory the rate of coarsening of TiCN is very small. Behaviour of coarsening of TiCN inclusions in the heating and holding stage cannot be taken into due consideration. Ti inclusions solid solution behaviour does partially exist in the heating process.[27] Via control of factors like rolling temperature, holding time and the rate of cooling, the quantity and size of Ti inclusions of large particles in the said steel can be controlled effectively, boosting strength.

2.1.12. TiN precipitation in maraging steel during vacuum arc remelting

Thermodynamic calculations imply that TiN inclusions tend to be somewhat unstable in the liquid bath during solidification, the segregation phenomenon in the mushy zone, enhances the TiN contents in the so called interdendritic liquid, which makes viable the very reactions of precipitation. [28] Inclusions characterization asserts that the nature of nucleation is heterogeneous, and the distribution of size is related to the density of nucleation sites and the N content, usually, the rate of melting plays a role on TiN size and the largest size of inclusions are found around mid radius.

2.1.13. Behaviour of TiN and Ti_2O_3 in contact with CaO – Al_2O_3 – SiO_2 – MgO slag

Thermodynamics calculations imply a different response of Ti_2O_3 and TiN when the stated slags are existing, one slag is rich in Al_2O_3 and second slag is seen to be rich in SiO_2. [29] Nitrogen released during reactions promotes the formation of so called pinholes which are supposed to act as a source of TiN attachment, it stands experimentally verified. Second of the two slags mentioned presents a better ability for TiN dissolution. Between some reactions involved and effective dissolution, a compromise has been found because intense TiN dissolution tends to enhance the pin hole formation in liquid steels.

2.1.14. TiO and TiN formation in micro alloyed steel

Calculation by tools like F.A.C.T show that the effective concentration of Ti precipitation is 200ppm. [30] If there is no Al; TiO is precipitated. Calculation of equilibrium between solid oxides and liquid steels, aluminum nitrides of titanium etc. indicate that at concentrations of nitrogen approaching 40 ppm, for the most part TiN particles tend to precipitate at liquidus temperature. [30] Coexistence of TiO with TiN precipitates has already been established in the environment of some oxide slags of Ca, Al, Si & Mg.

2.1.15. NMIs formation during solidification in the steel containing titanium

For solidification of Ti containing steel AH363U at the rates of cooling 50/100 Km^{-1}, analysis of formation of NMIs and solute segregation has been studied. [31] The simulations reveal that MnS particles form first and later TiN, Ti_2O_3 and then SiO_2. In the reference steel Si content is more than Ti content by a factor of 12. [31] This favours the formation of SiO_2, in the very last of portions of steels solidifying. The results have a tentative picture on the inclusions distribution in the steel ingot of the stated nomenclature. In actuality, the distribution relies on factors like the interaction of nonmetallic inclusions (NMIs) with the solidification front, the possibility of absorption of NMIs by it or the accumulation of the NMIs in the center of the ingot, which depends on size and location of the NMIs. More or less, these inclusions can also flow out to get assimilated by crystallizer slag. This in turn depends on inclusions distribution in some regions of the ingot.

2.1.16. Austenite microstructure refinement by Ti addition in steel

Casting experiments on S45C steel have been studied, with focus on the effect of addition of Ti on the as-cast gamma structure. Without the addition of Ti, γ structure comprises columnar grain of coarse nature. Ti addition between the range of 0.13-0.12% results in the formation of γ grains which are fine and equiaxed and are distributed across the whole thickness of ingot. [32] In the stated range, before the equiaxed gamma structure is formed because of primary crystals of Ti(C/N), the transition in δ dendrite structure takes place, which is columnar to equiaxed also termed 'CET'. Adding more Ti, tends to reform the γ grains which are coarse and columnar; correlation exists with the δ dendrite. Also, adding Ti tends to refine the grain by γ structure. Major affects are seen in the stated range, wherein the γ grains fully equiaxed develops and distribute over the whole ingot thickness . The size of as-cast γ grain decreases to that of less than δ dendrite equiaxed grain size.

2.1.17. TiN concentration optimization in microalloyed steel

On the basis of results, from the viewpoint of TiN precipitate forming in the austenite phase the ratio of Ti to N to be optimum is 3.42. [33]This optimum ratio can be attained when in the liquid steel the concentration level of N is 25ppm, and the amount of Ti added goes above 80ppm. [33] For the structure confined in liquid steel before the addition of Ti, the concentration level of N is also a key factor. If concentration of N is too high, too much TiN is formed; on the other hand, if N concentration is too low then there is too less TiN for austenite grain, also , after TiN has precipitated, some portion of N is still needed in the solid solution to facilitate the formation of carbonitrides and nitrides, which are supposed to enhance the mechanical properties via precipitation strengthening. Partial deoxidation of steel in also important, otherwise considerable portion of Ti introduced goes in to the oxide form. The assumption of such a study is that by means of Al, the liquid oxides precipitating at the steel deoxidation, are approximately entirely removed, If the assumptions incorporate some part of oxide phase precipitating with the existing Al_2O_3, between the liquid oxide solution and TiN, the Ti distribution will just vary.

The table below summarizes the main findings on Ti specific inclusions in different casting environments.

Table 2.
Inferences on Ti specific inclusions

Method	Case	Results
Coupling model study	Precipitation and coarsening of Ti inclusions in microalloyed steel	N and Ti predicted as solute concentrations by changed ki are different than those predicted by fixed ki referring to the equilibrium constant at initiation.
Thermodynamic analysis study	Assessment of precipitation, growth and control of MnS inclusions in U75V heavy rail steel	Segregation ratio of Mn is Lower than that of S during solidification, at solid fraction well above 0.9, MnS inclusion will precipitate. [34]
Material characterization study	Precipitation and growth of Ti inclusions in tyre chord steel	In the refining process; EDS and SEM show that main inclusions are rather in the form of TiO_x which tend to coexist with other inclusions.
Material characterization study	Characterization of TiNs formed during liquid steel solidification	Amount of Ti particles was seen to be too low in the liquid region. It indicates clearly that precipitation matures with solidification.
Thermodynamic analysis study	Extraction, precipitation and analysis of MnS-TiN complex inclusions in low sulphur steels	MnS inclusions somewhat nucleate on TiN inclusions heterogeneously on more lowering of temperature to 1570K. [35]
Study based on theoretical calculations	Influence of N and Ti addition to NiCrMoV steel	The study shows that Ti addition does two things; one, that it increases the activity level of molebdenum, and two, that it decreases the activity level of chromium.
Metallurgical analysis study	TiN in low alloyed steel during deformation and cooling	As the solidification process ends, the segregation of Ti takes place in interdendritic and intergranular zones. [36]
Study based on mechanical testing	Ti addition on behaviour of steel with medium carbon content	Ti addition has good effect on refinement of grain and so an effect on hardness, impact toughness and to an appreciable extent on some mechanical properties in general.
Study based on electrochemical experiments	Fe17Cr ferritic stainless steels and the effect of Ti on its corrosion behaviour	Two types of TiN precipitates in the stated steel exist, TiN precipitate and the TiN precipitate heterogeneous oxide core, consequently boosting corrosion resistance.
Thermodynamic analysis study	Ti stabilized 17Cr austenitic steels and the formation of inclusions	Thermodynamics analysis implies that pure particles of TiN are formed in the liquid phase, which is due to the high concentrations of N & Ti solutes in the molten steel.
Material characterization study	TiN precipitation in maraging steel during vacuum arc remelting	Via control of factors like rolling temperature, holding time and the rate of cooling, the quantity and size of Ti inclusions of large particles in the said steel can be controlled effectively, boosting strength.
Study based on material characterization	TiN and Ti2O3 inclusions in contact with CaO-Al2O3-SiO2-MgO	Inclusions characterization asserts that the nature of nucleation is heterogeneous, and the distribution of size is related to the density of nucleation sites and the N content.
Experimental study	TiO and TiN formation in microalloyed steel	Nitrogen released during reactions promotes the formation of so called pinholes which are supposed to act as a source of TiN attachment, it stands experimentally verified.
Computational method study	Solute segregation and NMI formation during solidification in the steel containing Ti	The simulations reveal that MnS particles form first and later TiN, Ti_2O_3 and then SiO_2. In the reference steel Si content is more than Ti content by a factor of 12. [37]

Material characterization study	Microstructure refinement by Ti addition in S45C steel	Without the addition of Ti, γ structure comprises columnar grain of coarse nature. Ti addition between the range of 0.13-0.12% results in the formation of γ grains which are fine and equiaxed and are distributed across the whole thickness of ingot. [38]
Experimental study	TiN concentration optimization in microalloyed steel	TiN precipitate forming in the austenite phase the ratio of Ti to N to be optimum is 3.42. [39]

In order for some core findings to be validated, some industrial samples from difference stages of casting were procured, prepared and characterized. It is of interest to highlight that there was coherence seen with the theoretical findings. However, the idea was to keep the compilation qualitative based on findings of other researchers. Some graphics below will correlate basic parameters of interest. Metallography for surface preparation alongside characterization have indicated that inclusions in particular those related to Ti have shown effects which seem to enhance the properties.

In addition, the surface finish and the refinement of grain in OM images, the expected presence of TixOy layer in the SEM images and the surface characteristics differences in the Raman spectroscopy images are pictorially presented based on most suitable characterization results of two out of twelve industrial samples prepared. Grain size in many quantitative studies has been between 20-40 um and mean of these numbers can be safely assumed as a representative value however the lattice parameters stand variable in general. [40,41] The two fold increase in the impact toughness in other related experimental works is the result of grain refinement. However, these are only the starting points of Ti trace effects on steel. It is to be emphasized here that the main inferences related to the process of casting and Ti related inclusions are rather clearly stated point-wise in the final conclusion section. However, figure 1 to 4 show surface finish, grain refinement, TixOy film presence and spectral intensity differences without and with Ti related inclusions:

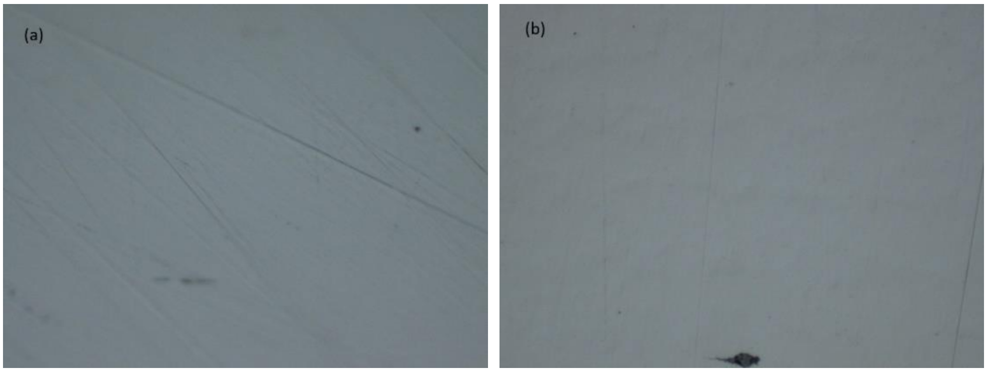


Fig. 1. OM micrograph of steel specimen with Ti traces at 50x magnification; (a) before surface preparation; (b) after metallography showing better surface

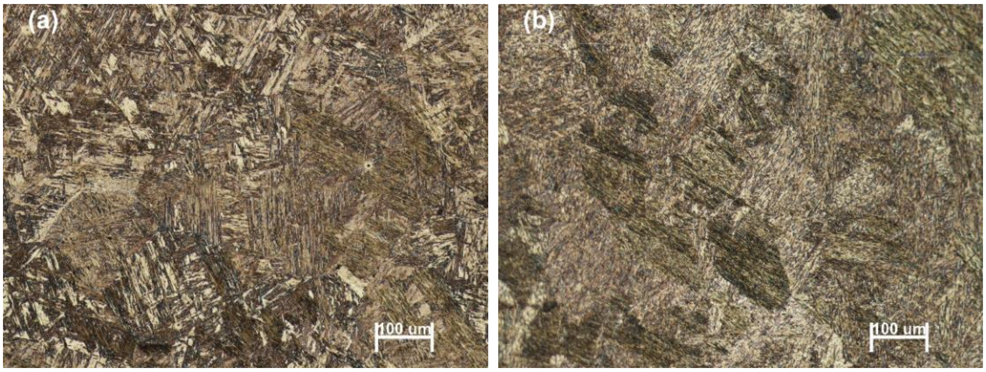


Fig. 2. OM micrograph of steel specimen with slightly more Ti traces showing areas with grain refinement; (a) coarser grain about 40um; (b) finer grain about 20um

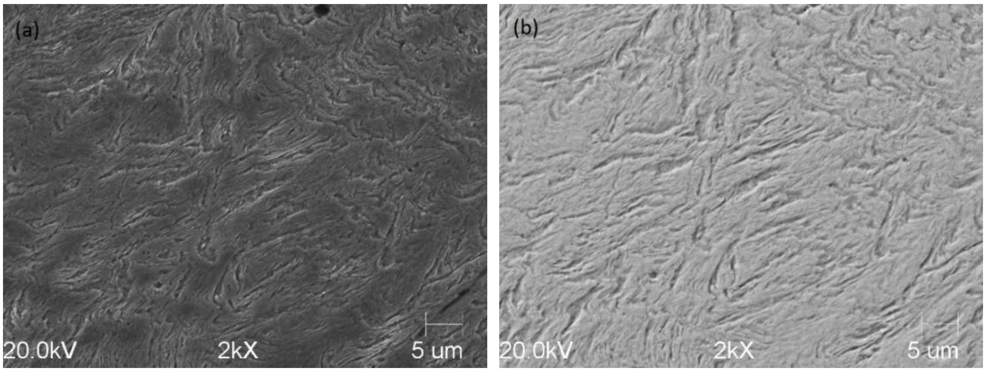
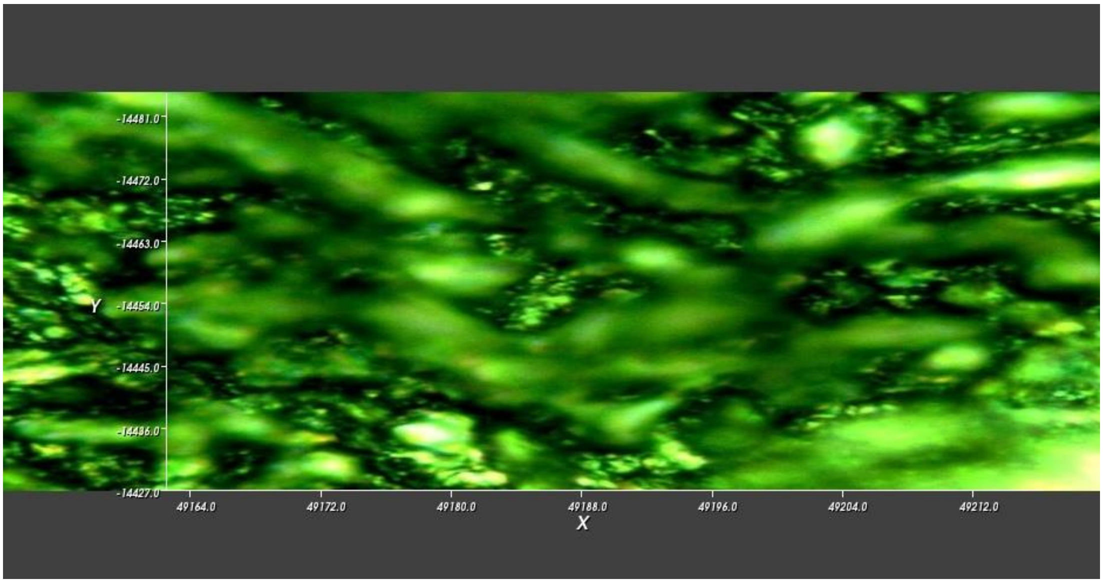
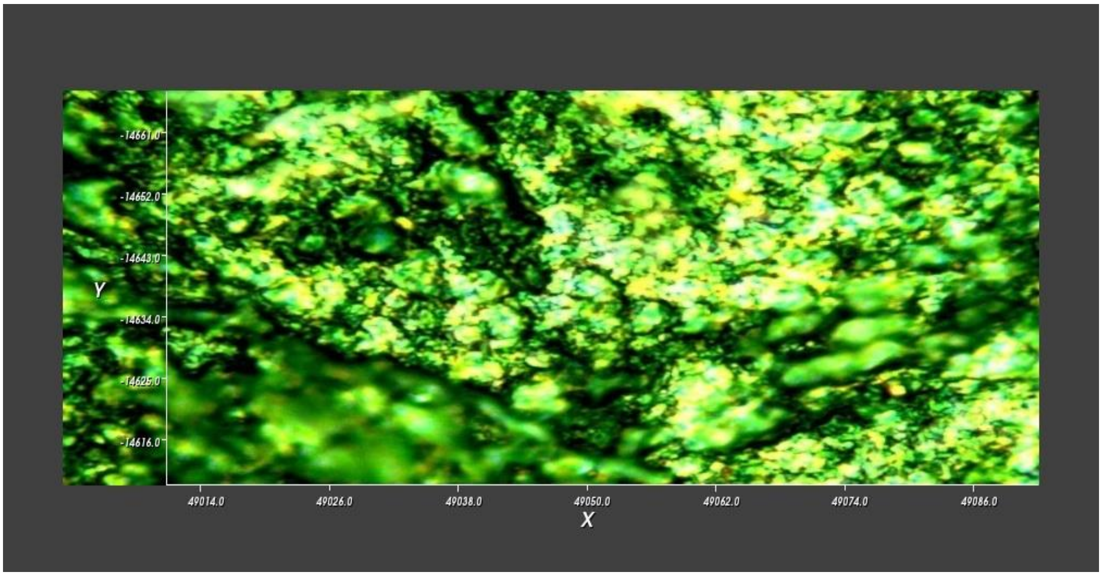


Fig. 3. SEM micrographs of steel specimen; (a) with FexOy areas with darkness; (b) cleaner surface attributed to TixOy film



a)



b)

Fig. 4. Raman spectrograph of mild steel samples a) without Ti traces, b) with considerable Ti traces

3. Discussion

Optimization of NMIs improves metal properties. In continuous casting of steel special care must be taken to not allow reoxidation, nozzle clogging and entrapment of slag. Review of fluid flows in casting and metal processing clearly asserts the significance of flows in the characteristics of steel making vessels. In certain complex alloys, thermochemical analysis shows that the oxygen content and the initial metal composition are key factors in metal modification. Numerical simulation of macrosegregation indicates that in the mushy zone the solid phase temperatures and distributions are somewhat unstable. When some of the alloying elements are shared, the equilibrium amount of other precipitates may decrease due to amount available for the next process to follow. In the reliable process modelling of slag reduction, geometry of the elementary reaction is crucial. The demand for the elements like titanium has increased due to advancement in metal industry. Group IVa and Va elements have much effect on quench hardening of steel, including aluminium, they do not have much effect on the tensile strength. Rare earth elements are good scavengers of steel because of their desulphurizing and deoxidizing power. Optimization of oxide inclusion composition concludes that at low solute concentrations in microalloyed steel, titanium has a significant role, contrary to the precipitations at higher concentrations. Using the effect of metal nitride gas equilibration, effect of aluminium on solubility of nitrogen and solubility product of aluminium nitride, AlN is seen to be formed at critical values of aluminium and nitrogen. Before calcium addition in certain cases the microinclusions seem to be alumina and after addition they are transformed in to calcium aluminates with small amounts of manganese and sulphur oxides.

During precipitation and coarsening of Ti inclusions, the mushy zone goes through coexisting phase zones while solidification is taking place. Precipitation of MnS inclusion implies that segregation ratio of Mn is lower than that of S. At fs well above 0.9 MnS precipitates, Ti_xO_y compounds will precipitate before MnS and after TiS. In the refining process, EDS and SEM indicate that main inclusion are TiO_x which tend to coexist with some other oxides. In medium carbon steel with different Ti & N contents, that is subject to characterization, observation is that oxides and sulphides are normally detected. The Mn and S activity level in the vicinity of TiN increases with depleting N & Ti. MnS inclusions tend to nucleate on TiN inclusion homogeneously. N & Ti inclusions have shown effects on NiCrMoV steels, for instance the addition of Ti tends to increase the hardness in such tempered steels. In low alloyed steels, as the solidification process ends, the segregation of Ti takes place in interdendritic and intergranular zones. Ti addition has good effect on refinement of grain and so a good effect on hardness and impact toughness especially in the medium carbon steels. Ti addition to the ferritic stainless steels has an evident effect on corrosion resistance relating to the precipitation of TiN. Pure particles of TiN are formed in the liquid phase which is due to high concentrations of N & Ti in the molten steels of austenitic nature. Possiblity of TiCN inclusions precipitation is also observed in tyre cord steel, boosting its strength to some extent. In the vacuum arc remelting, inclusions characterization has asserted that the nature of nucleation is heterogeneous and the distribution of size in TiN precipitates is related to the density of the nucleation sites and N content. Ti_2O_3 is observed to coexist with TiN in flurry of oxides of slag, some rich in Al_2O_3 and the other SiO_2. If Al, is present TiO tends to precipitate. Usually TiN precipitates in micro alloyed steel and the effective concentration of Ti and N are 200ppm and 40ppm respectively. TiNs formation during solidification have been analyzed to see that MnS particles form first, then TiN & Ti_2O_3 and in the end SiO_2 , wherein Si content is more than Ti by a factor of 12. CET of grain structure is observed in as-cast steels with the Ti addition in certain range, also grain refinement is seen to some extent in austenitic steels.

4. Conclusions

Different types of casting techniques are in practice in the industry. The main factors stand out to be processing times and temperatures alongside the compositions involved. The process has many stages and parameters and therefore multiple factors correlated in certain environments. Much depends on the layout of the process and also the type of steel being manufactured. Slag needs to be addressed for desirable properties of the steel alloys produced. Surface and bulk properties are connected to the better carrying out of the casting process beyond doubt. Precipitation has seemed to mature as the solidification is almost complete in most scenarios. Desirable phase changes can also be addressed by optimizing the process parameters of casting. Elemental ratios have been higlighted in TiN for optimum results in certain cases.
For correlation and ease of understanding the main point-wise conclusions rather related to the casting aspects are summarized below:

a) Inside the mushy zone, solid phase part distributions and the impurities' temperatures are unstable.
b) In case of some alloying elements being shared the equilibrium amount of second precipitated phase may be decreased.
c) With changing N partial pressures and using metal nitride gas equilibration technique, when the amount of Al was increases, the solubility of N in liquid Fe decreases.
d) Segregation ratio of Mn is lower than that of S during solidification, at solid fraction well above 0.9, MnS inclusion will precipitate.
e) In the refining process; EDS and SEM show that main inclusions are rather in the form of TiO_x which tend to coexist with other inclusions.
f) MnS inclusions somewhat nucleate on TiN inclusions heterogeneously on lowering of temperature to 1570K.
g) Ti addtion increases the activity level of molebdenum and decreases the activity level of chromium.
h) Thermodynamic analysis implies that pure particles of TiN are formed in the liquid phase, which is due to the high concentrations of N & Ti solutes in the molten steel.
i) Controlling the factors like rolling temperature, holding time and the rate of cooling, the quantity and size of Ti inclusions of large particles can be controlled effectively, boosting strength.
j) Inclusion characterization asserts that the nature of nucleation is heterogeneous, and the distribution of size is related to the density of nucleation sites and the N content, keeping in view the TiN and TixOy interactions.

k) Nitrogen released during reactions promotes the formation of so called pinholes which are supposed to act as a source of TiN attachment.

Further, it can be stated with confidence based on the inferences drawn by the existing research that trace elements like Ti in the form of TiN, TixOy, TiC as well as TiCN seem to exist in appreciable amounts and their presence can add to the properties like surface hardness, corrosion resistance, impact toughness and strength, depending on the type of steel and casting conditions and the controlled amount of inclusions coexisting with general inclusions other than Ti related ones.

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