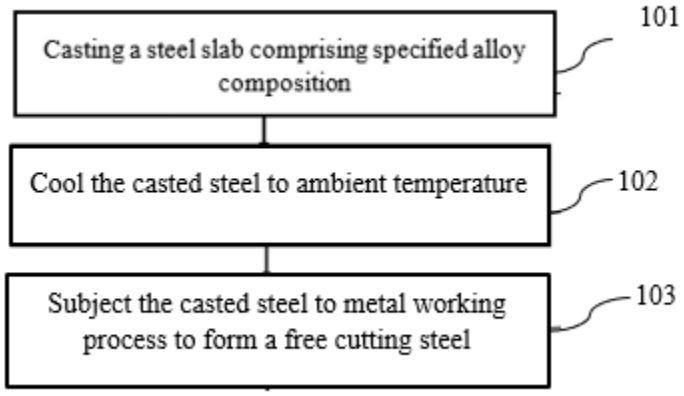


Fig. 1

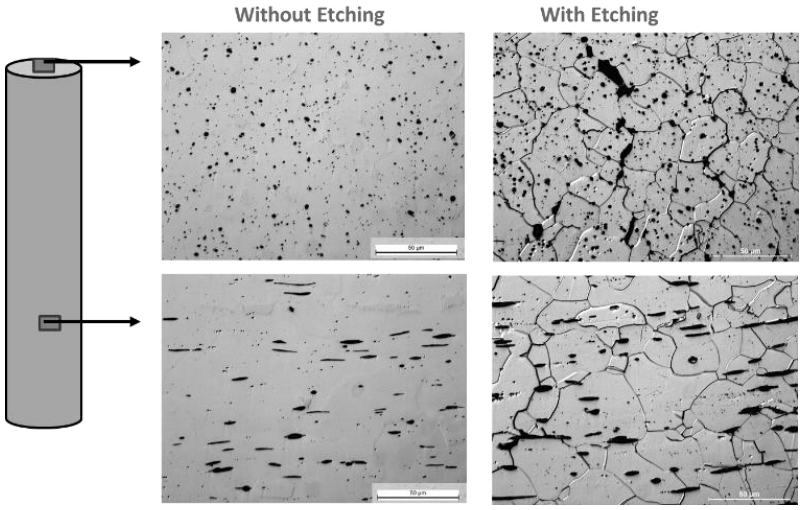


Fig. 2a

GOPINATH A S
IN/PA-1852
OF K&S PARTNERS
AGENT FOR THE APPLICANT

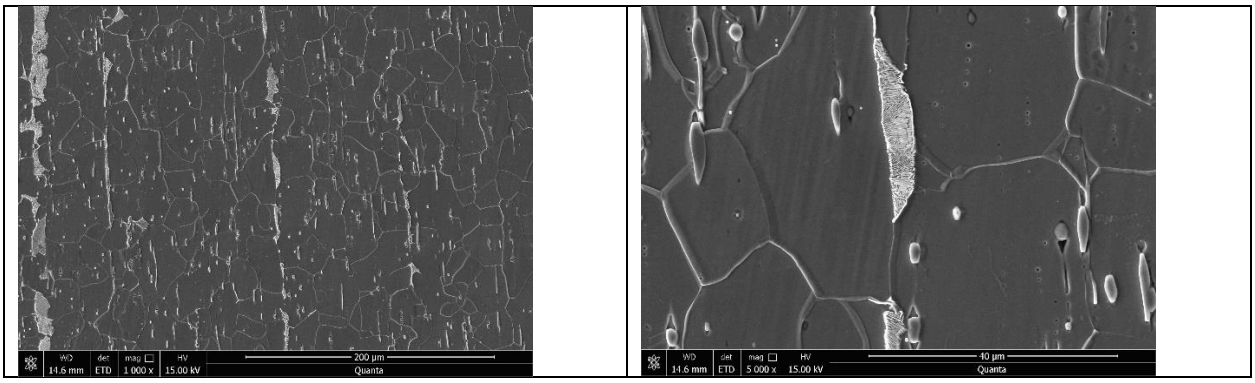


Fig. 2b

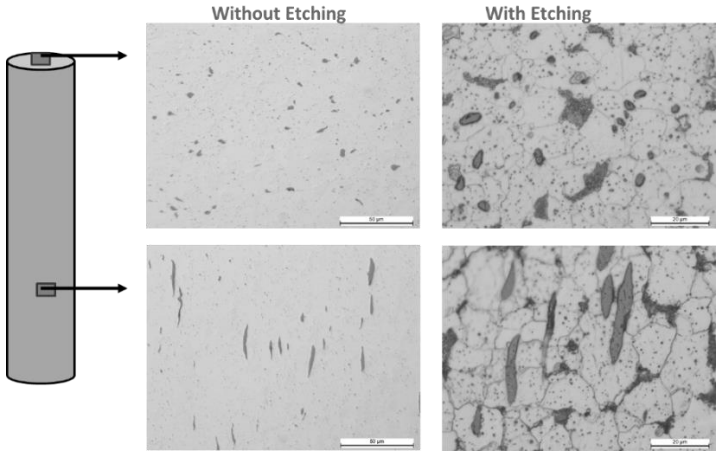
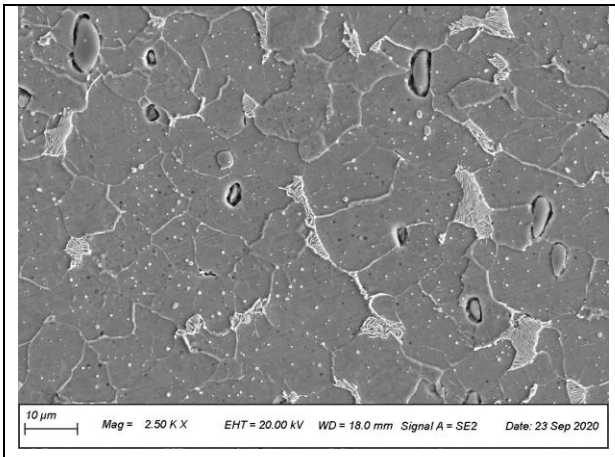


Fig. 3

GOPINATH A S
IN/PA-1852
OF K&S PARTNERS
AGENT FOR THE APPLICANT



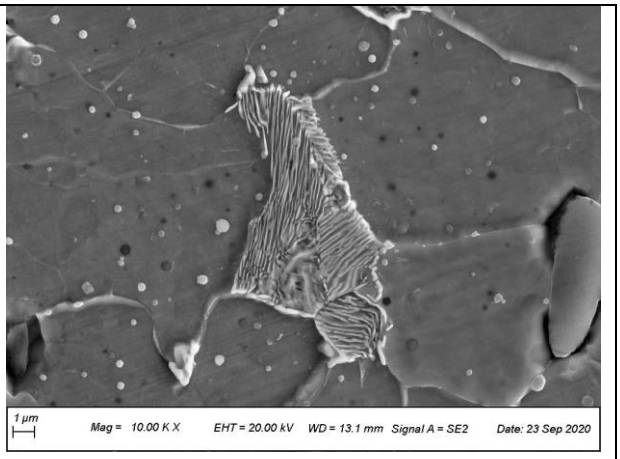
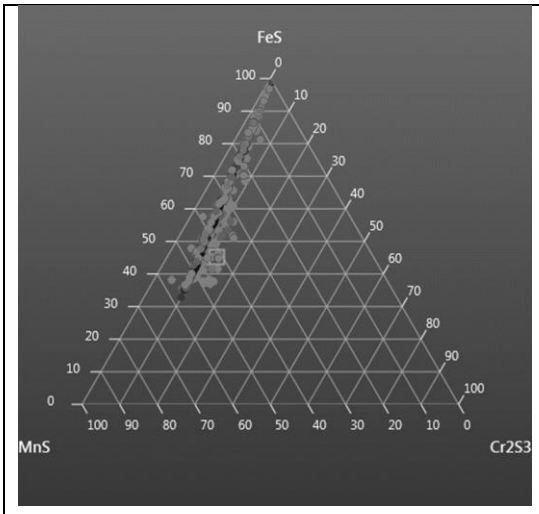
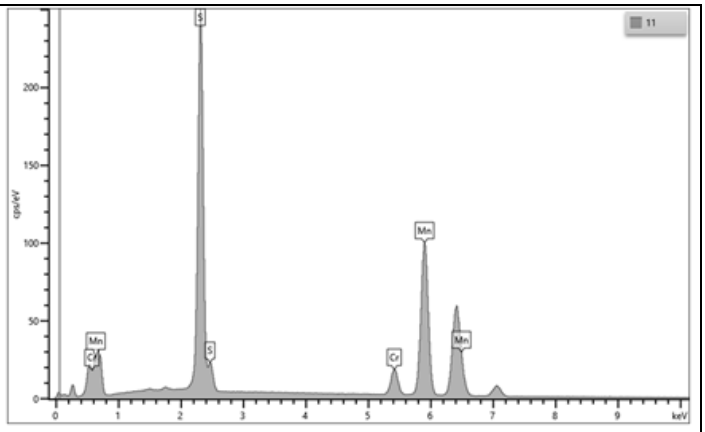


Fig. 4



a)



b)

Fig. 5

GOPINATH A S
IN/PA-1852
OF K&S PARTNERS
AGENT FOR THE APPLICANT

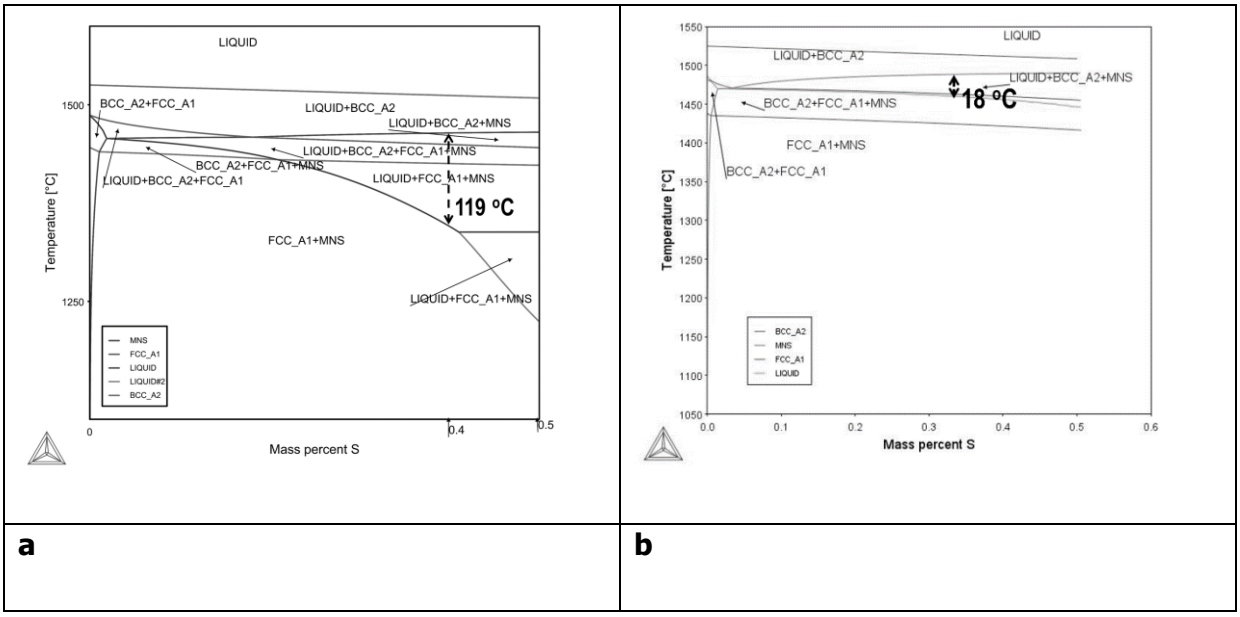


Fig. 6

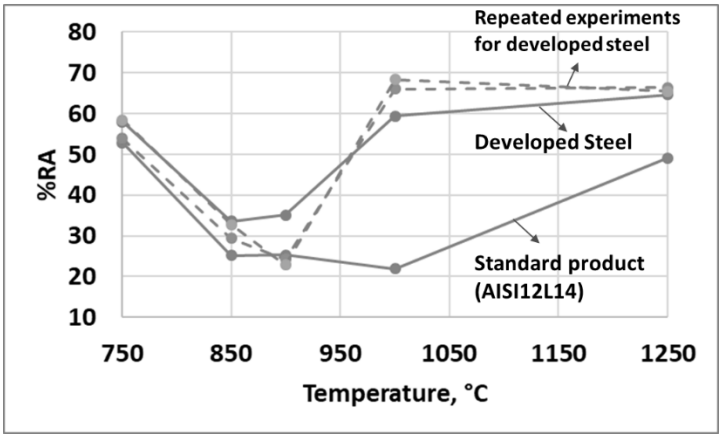


Fig. 7

GOPINATH A S
IN/PA-1852
OF K&S PARTNERS
AGENT FOR THE APPLICANT

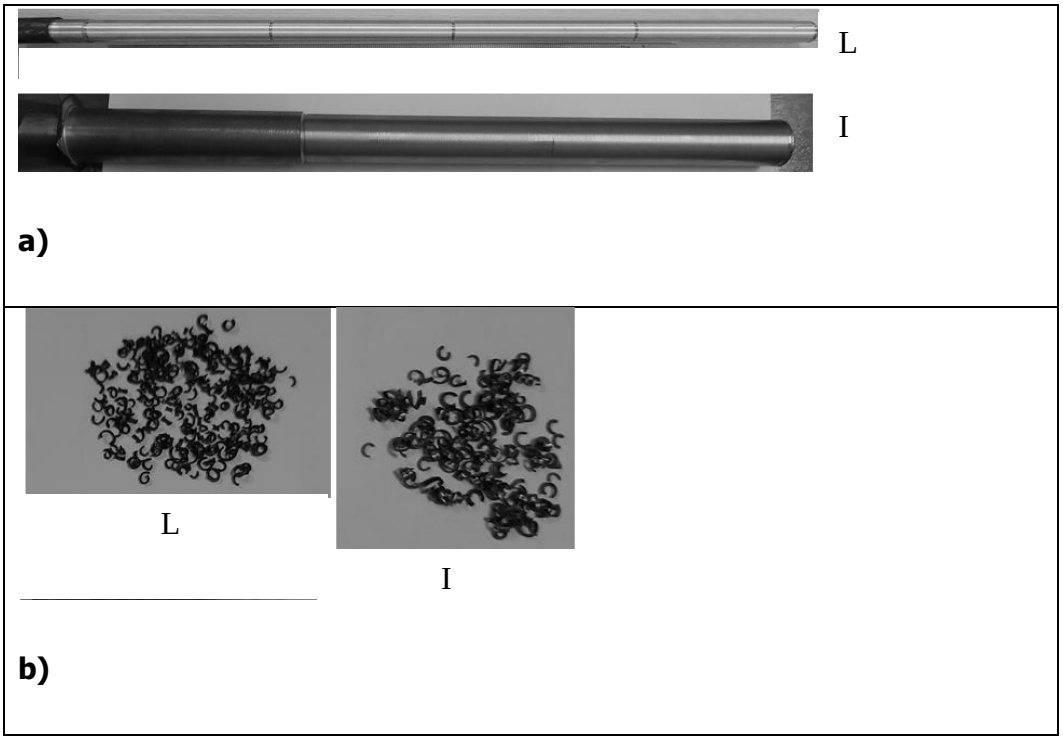


Fig. 8 (Keep the scale)

GOPINATH A S
IN/PA-1852
OF K&S PARTNERS
AGENT FOR THE APPLICANT

FORM 2

THE PATENTS ACT 1970

[39 OF 1970]
&
THE PATENTS RULES, 2003

COMPLETE SPECIFICATION

[See section 10; rule 13]

TITLE: "A FREE CUTTING STEEL AND A METHOD OF MANUFACTURING THEREOF"

Name and Address of the Applicant:
TATA STEEL LIMITED of Jamshedpur - 831001, Jharkhand, India.

Nationality: Indian

The following specification particularly describes the invention and the manner in which it is to be performed.

TECHNICAL FIELD

Present disclosure, in general, relates to a field of metallurgy. Particularly, but not exclusively, the present disclosure relates to steels. Further, embodiments of the present disclosure disclose a free cutting steel and a method of manufacturing the free cutting steel.

BACKGROUND OF THE DISCLOSURE

Steel is an alloy of iron (Fe), carbon (C), and other alloying elements such as Phosphorous (P), Sulphur (S), Manganese (Mn), Silicon (Si), etc. Because of its high tensile strength and low cost, steel is considered as a major component in wide variety of applications. Some of the applications of the steel may include buildings, ship building, tools, automobiles, machines, bridges, and numerous other applications.

Generally, in manufacturing industries steel having high machinability is preferred. Typically, free cutting steels are employed for manufacturing which exhibit the high machinability. Conventional free cutting steels include additives such as lead (Pb), which improves the machinability of the free cutting steel. Inclusion of lead (Pb) enables higher cutting speed, extended tool life, improved chip formation and enables easy removal of swarf during machining, which results in lower energy consumption. However, certain regulations prohibit the use of heavy metal elements including lead (Pb) due to its highly toxic and health hazardous nature. Therefore, usage of lead (Pb) poses a negative impact on the environment, which is undesired.

With advancements in technology, bismuth, tellurium have been tested as an alternative for lead. However, in tests with high-speed steel tools and lubricant, the leaded steel showcased better performance in terms of production rate, surface finish and chip formation. Further, in tests with coated carbide tools, the steel with the alternative additives showcased low tool wear but showed poorer chip formation than the leaded steel. Furthermore, the alternative additives such as bismuth and tellurium are expensive when compared to lead.

Present disclosure is directed to overcome one or more limitations stated above or any other limitations associated with the known arts.

SUMMARY OF THE DISCLOSURE

One or more shortcomings of the prior art are overcome by a free cutting steel and the method of manufacturing as claimed and additional advantages are provided through the free cutting steel and the method as claimed in the present disclosure. Additional features and advantages are realized through the techniques of the present disclosure. Other embodiments and aspects of the disclosure are described in detail herein and are considered a part of the claimed disclosure.

In one non-limiting embodiment of the present disclosure a free cutting steel is disclosed. The free cutting steel includes an alloy composition in weight (wt%) percentage of carbon (C) at about 0.07% to about 0.09%, manganese (Mn) at about 0.5% to about 0.6%, silicon (Si) up-to 0.05%, phosphorus (P) at about 0.04% to about 0.09%, sulphur (S) at about 0.38% to about 0.45%, chromium (Cr) at about 0.7% to about 0.9%, nitrogen (N) up-to 60ppm, oxygen (O) up-to 0.012%, and the balance being Iron (Fe) optionally along with incidental elements. Further, the free cutting steel with said alloy composition includes ferrite and pearlite microstructure.

In an embodiment, sulphur (S) and chromium (Cr) in the alloy composition expands crystallization temperature ensuring crystallization by monotectic reaction. Inclusion of at least one of the chromium (Cr) and manganese (Mn) in the alloy composition forms elongated shape sulphide inclusions in the ferrite and pearlite microstructure.

In an embodiment, the free cutting steel exhibits hardness of about 146 HV to about 159 HV.

In an embodiment, the microstructure of the free cutting steel is represented by, in area%, ferrite microstructure in the range of about 90% to about 95% and pearlite microstructure in the range of about 5% to about 10%.

In an embodiment, the microstructure of the free cutting steel exhibits grain size in the range of about 10 µm to about 15 µm.

In an embodiment, the free cutting steel is structured to have substantially large solidus temperature resulting in large sulphide inclusions.

In another non-limiting embodiment of the present disclosure, a method for manufacturing a free cutting steel is disclosed. The method includes casting a steel slab which includes an alloy composition in weight (wt%) alloy composition in weight (wt%) percentage of carbon (C) at about 0.07% to about 0.09%, manganese (Mn) at about 0.5% to about 0.6%, silicon (Si) up-to 0.05%, phosphorus (P) at about 0.04% to about 0.09%, sulphur (S) at about 0.38% to about 0.45%, chromium (Cr) at about 0.7% to about 0.9%, nitrogen (N) up-to 60ppm, oxygen (O) up-to 0.012%, and the balance being Iron (Fe) optionally along with incidental elements. Further, the casted steel is cooled to ambient temperature. Furthermore, the cooled casted steel is subjected to metal working process to form a free cutting steel. The inclusion of at least one of the chromium (Cr) and manganese (Mn) in the alloy composition forms elongated shape sulphide inclusions in the ferrite and pearlite microstructure.

The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS

The novel features and characteristics of the disclosure are set forth in the appended claims. The disclosure itself, however, as well as a preferred mode of use, further objectives, and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiments when read in conjunction with the accompanying figures. One or more embodiments are now described, by way of example only, with reference to the accompanying figures wherein like reference numerals represent like elements and in which:

Fig. 1 is a flowchart illustrating a method for manufacturing a free cutting steel, according to an exemplary embodiment of the present disclosure.

Fig. 2a illustrates optical micrographs taken from cross section and longitudinal section of a conventional free cutting steel having lead as additive.

Fig. 2b illustrates a scanning electron microscope (SEM) micrograph which showcases presence of ferrite and pearlitic structure in the conventional free cutting steel having lead as additive.

Fig. 3 illustrates optical micrographs of the free cutting steel, in accordance with an embodiment of the present disclosure.

Fig. 4 illustrates a scanning electron microscope (SEM) micrograph of the free cutting steel, in accordance with an embodiment of the present disclosure.

Figs. 5a and 5b are graphs illustrating the energy dispersive spectroscopy (EDS) mapped for the free cutting steel, in accordance with an embodiment of the present disclosure.

Figs. 6a and 6b illustrates phase diagrams calculated based on chemistry of developed steel according to present disclosure and compared with lead added free cutting steel.

Fig. 7 is a graph illustrating percentage of reduction in area (%RA) values which are plotted against testing temperature during hot tensile test, in accordance with an embodiment of the present disclosure.

Fig. 8a and 8b illustrates a comparison of surface finish and chip size between free cutting steel according to present disclosure and lead added free cutting steel.

The figures depict embodiments of the disclosure for purposes of illustration only. One skilled in the art will readily recognize from the following description that alternative embodiments of the system and method illustrated herein may be employed without departing from the principles of the disclosure described herein.

DETAILED DESCRIPTION

The foregoing has broadly outlined the features and technical advantages of the present disclosure in order that the detailed description of the disclosure that follows may be better understood. Additional features and advantages of the disclosure will be described hereinafter which forms the subject of the claims of the disclosure. It should be appreciated by those skilled in the art that, the conception and specific embodiments disclosed may be readily utilized as a basis for modifying

other materials, products, methods, and processes for carrying out the same purposes of the present disclosure. It should also be realized by those skilled in the art that, such equivalent method do not depart from the scope of the disclosure as set forth in the appended claims. The novel features which are believed to be characteristics of the disclosure, to its composition and method, together with further objects and advantages will be better understood from the following description when considered in connection with the accompanying figures. It is to be expressly understood, however, that each of the figures is provided for the purpose of illustration and description only and is not intended as a definition of the limits of the present disclosure.

In the present document, the word "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any embodiment or implementation of the present subject matter described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments.

While the disclosure is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and will be described in detail below. It should be understood, however that it is not intended to limit the disclosure to the particular forms disclosed, but on the contrary, the disclosure is to cover all modifications, equivalents, and alternatives falling within the scope of the disclosure.

The terms “comprises”, “comprising”, or any other variations thereof, are intended to cover a non-exclusive inclusions, such that a method comprises a list of steps does not include only those steps but may include steps not expressly listed or inherent to such setup or device. In other words, one or more steps in a method proceeded by “comprises… a” does not, without more constraints, preclude the existence of other steps.

Embodiments of the present disclosure discloses a free cutting steel and a method for manufacturing or producing the free cutting steel. The conventional free cutting steels include additives such as lead (Pb), which improves the machinability property of the free cutting steel. However, certain regulations prohibit the use of heavy metal elements including lead (Pb) due to its highly toxic and health hazardous nature. Therefore, usage of lead (Pb) poses a negative impact on the environment, which is undesired. Accordingly, the present disclosure discloses the free cutting steel and the method for manufacturing the free cutting steel which employ chromium as

additive in the alloy composition. Addition of chromium aids the free cutting steel to exhibit same mechanical properties as of the free cutting steel, which includes lead (Pb) as additive, and without posing any environmental hazardous.

In the method of manufacturing the free cutting steel, a first step may include casting the steel comprising an alloy composition in weight (wt%) percentage of carbon (C) at about 0.07% to about 0.09%, manganese (Mn) at about 0.5% to about 0.6%, silicon (Si) up-to 0.05%, phosphorus (P) at about 0.04% to about 0.09%, sulphur (S) at about 0.38% to about 0.45%, chromium (Cr) at about 0.7% to about 0.9%, nitrogen (N) up-to 60ppm, oxygen (O) up-to 0.012%, and the balance being Iron (Fe) optionally along with incidental elements. Further, the method includes cooling the casted steel to an ambient temperature. Furthermore, the method includes subjecting the casted steel to a metal working process to form a free cutting steel.

The addition of chromium in right ratios with the manganese and sulphur may aid in substantially increasing solidus temperature resulting in large sulphide inclusions. Also, the addition of chromium may improve machinability. Further, addition of chromium may act as an additive during machining which helps in easy cutting, better surface finish and smaller chip formation, which are essential properties to be exhibited by the free cutting steels. Furthermore, the chromium in the alloy composition eliminates formation of compounds prior to, during and after transformation of austenite to ferrite phase. Additionally, the chromium may aid in elongated distribution of sulphide inclusions which may enhance the surface properties of the free cutting steel.

Henceforth, method of manufacturing the free cutting steel having chromium (Cr) of the present disclosure is explained with the help of figures. However, such exemplary embodiments should not be construed as limitations of the present disclosure since the method may be used on other types of steels where such need arises. A person skilled in the art may envisage various such embodiments without deviating from scope of the present disclosure.

Fig. 1 is a flowchart depicting a method for manufacturing the free cutting steel. In the present disclosure, mechanical properties such as machinability, better surface finish, smaller chips formation and microstructure of the free cutting steel may be improved. The free cutting steel may

be manufactured by adding chromium (Cr), aiding in improving the mechanical properties of the free cutting steel without addition of lead (Pb), which is hazardous to environment. The method is now described with reference to the flowchart blocks.

At **block 101**, an alloy including an alloy composition in weight (wt%) percentage of carbon (C) at about 0.07% to about 0.09%, manganese (Mn) at about 0.5% to about 0.6%, silicon (Si) up-to 0.05%, phosphorus (P) at about 0.04% to about 0.09%, sulphur (S) at about 0.38% to about 0.45%, chromium (Cr) at about 0.7% to about 0.9%, nitrogen (N) up-to 60ppm, oxygen (O) up-to 0.012%, and the balance being Iron (Fe) optionally along with incidental elements, may be casted. As an example, liquid alloy with the above-mentioned composition and range of alloying elements may be continuously casted into a steel billets. In an embodiment, the steel billet may be are smaller billet. The alloying elements may be melted to liquid form in at least one of but not limited to an electric arc furnace. In an embodiment, the electric arc furnace may be employed to melt the alloying elements which may aid in controlling the composition of sulphur (S).

At **block 102** and as seen in **Fig. 1**, the method may include cooling the casted steel to an ambient temperature. In an embodiment, the ambient temperature may be a temperature equal to a room temperature. Further, the casted steel may be subjected to cooling by without any external coolers or may be subjected to cooling with the aid of external coolers.

At block **103**, the method may include subjecting the steel billets obtained by the casting process to a metal working process to produce the free cutting steel. In an embodiment, the metal working process may be including but not limited to wire rolling..

The free cutting steel, formed by the method of the present disclosure may include ferrite and pearlite microstructure. The microstructure of the free cutting steel may be represented by, in area%, ferrite microstructure in the range of about 90% to about 95% and pearlite microstructure in the range of about 5% to about 10%. Further, the microstructure of the free cutting steel may exhibit grain size in the range of about 10 µm to about 15 µm. In an embodiment, the free cutting steel may exhibit ferrite grain boundaries after a shaping process which may be formed due to the inclusion of chromium (Cr). Further, the free cutting steel formed by the method of the present disclosure may exhibit hardness in the range of about 146HV to about 159HV.

In an embodiment, the controlled addition of manganese (Mn) and chromium (Cr) may improve machinability by increasing the size of sulfide inclusions. The controlled addition of manganese (Mn) and Chromium (Cr) may lead to elongated shape of the sulphide inclusions in the ferrite and pearlite microstructure of the free cutting steel. The elongated shape of sulphide inclusions may be achieved by addition of the chromium (Cr) in the alloy composition which may substantially increase the solidus temperature. That is the time for conversion of liquid steel to solid may be substantially increased.

Fig. 2a illustrates optical micrographs taken from a cross section and a longitudinal section of a conventional free cutting steel having lead as the additive. The micrographs showcases elongated inclusion in the microstructure when taken from the longitudinal section and a circular inclusion when taken from the cross section. The conventional free cutting steel having lead as the additive includes a grain size in the range of 10-18 microns with hardness in the range of 107-112HV. Furthermore, referring to **Fig. 2b** which illustrates a scanning electron microscope (SEM) micrograph which showcases presence of ferrite and pearlitic structure in the conventional free cutting steel having lead as the additive.

Referring to **Figs. 3 and 4**, which illustrates optical micrographs of the free cutting steel having the composition of the present disclosure. The free cutting steel of the present disclosure includes chromium (Cr) which may be employed as additive element to enhance the machinability. The controlled addition of chromium (Cr) and manganese (Mn) provides elongated sulphide inclusions which may be viewed in longitudinal section and circular shape in the cross-sectional micro-structure. The hardness of the free cutting steel achieved may be in the range of about 146HV to about 159HV which is greater than the hardness of the conventional free cutting steel having lead as the additive. Further, the scanning electron microscope (SEM) micrograph as seen in **Fig. 4**, showcases the presence of pearlite in the microstructure of the steel.

Further, as seen in **Figs. 5a and 5b**, an energy dispersive spectroscopy (EDS) has been mapped for free cutting steel of the present disclosure. From the energy dispersive spectroscopy (EDS), manganese (Mn), chromium (Cr) and sulphur (S) has been confirmed to be present in the inclusions [as seen in Fig. 5a]. Furthermore, the energy dispersive spectroscopy (EDS) showcased

that chromium (Cr) has been also traced in some of the inclusions [as seen in Fig. 5b]. Further, it is confirmed that, there is no formation of grain boundary segregation, because of the presence of chromium (Cr) in the alloy composition.

Referring now to **Fig. 6a and 6b**, which illustrates a phase diagram calculated based on the chemistry of the free cutting steel manufactured according to the present disclosure and conventional free cutting steel having lead as the additive. **FIG. 6a** illustrates phase diagram of the free cutting steel according to the present disclosure and **FIG.6b** illustrates phase diagram of free cutting steel having lead as the additive. From **FIG.6a** it can be noted that the crystallization temperature range is only expanded by "chromium (Cr) and sulphur (S) increment". The calculated phase diagram of the free cutting steel of present disclosure in comparison with the calculated result of the conventional lead added free cutting steel can be seen in **Fig. 6a and 6b**. The crystallization temperature range for sulphide inclusions in conventional lead added free cutting steel was calculated as 18°C. In contrast, the temperature range of the free cutting steel of present disclosure expanded by more than six times, to 119°C.

Following portions of the present disclosure, provides details about the role of proportion of each element in the composition of the free cutting steel.

Carbon (C) may be used in the range of about 0.07wt% to about 0.09wt%, which may provide the appropriate hardness to the free cutting steel. Further, variation of the carbon beyond the specified range in the composition, may lead to difficulty in machining the free cutting steel.

Manganese (Mn) may be used in the range of about 0.5wt% to about 0.6wt%, chromium in the range of about 0.7wt% to about 0.9wt% and Sulphur (S) may be used in the range of about 0.38wt% to 0.45wt%. The ratio of composition of the manganese, chromium and sulphur provides may be required to achieve the desired sulphide inclusions of elongated shape and results in smaller chip formation during machining of the free cutting steel.

Further, the free cutting steel may include silicon (Si) up-to 0.05%, phosphorus (P) at about 0.04% to about 0.09%, nitrogen (N) up-to 60ppm and oxygen (O) up-to 0.012%, which are required to manufacture steel. Table 1 provided below illustrates a range of elements in the alloy composition of the free cutting steel with chromium (Cr) and conventional lead added free cutting steel.

Name/wt%	C	Mn	Si	P	S	Cr	N	O	Pb	Cost/ton (Rs)
Conventional lead added steel	0.15 Max	0.85 - 1.15	0.05 Max	0.040 - 0.090	0.26 - 0.35	-	0.006 max	0.012 max	0.15 - 0.35	Costly
Cr added free cutting steel	0.07-0.09	0.5-0.6	0.05 max	0.040 - 0.06	0.38-0.45	0.7-0.9	0.006 max	0.012 max	NIL	Economical

Table 1

Exemplary Experimental analysis:

Further embodiments of the present disclosure will be now described with experiments conducted to compare the conventional free cutting steel having lead as the additive with the free cutting steel manufactured by the method and composition as disclosed in the present disclosure.

Machinability test:

Machinability tests has been performed with the conventional free cutting steel having lead as the additive and the free cutting steel having chromium (Cr). All the machinability parameters, such as surface finish, chip size and tool wear has been captured and compared with the results of the conventional free cutting steel having lead as the additive. The tool wear data has been measured after cutting and have been recorded as showcased in the Table 2, below. From the table 2, it is evident that, the tool wear of the free cutting steel having chromium (Cr) is measured to be comparable and similar to the conventional free cutting steel having lead as the additive. Further, the surface finish of both the steels have been captured and chips formed during machining of the the free cutting steel having chromium (Cr) and the conventional free cutting steel having lead as the additive have been collected for comparison, which showcased that the surface finish and the chips formation of the free cutting steel having chromium (Cr) is similar to the conventional leaded free cutting steel, where the nature of chips were curly in shape and were easily broken into small sizes. **Fig.8** illustrates a comparison of surface finish and chip size between free cutting free cutting steel according to present disclosure and lead added free cutting steel. **Fig. 8a** illustrates comparison of surface finish between free cutting steel according to present disclosure [depicted

as I] and lead added free cutting steel [depicted as L]. **Fig. 8b** illustrates comparison of chip size between free cutting steel according to present disclosure [depicted as I] and lead added free cutting steel [depicted as L].

Cutting condition	Conventional steel	Cr added free cutting steel
Cutting Speed= 70m /min Feed=0.1mm/rev Depth of Cutting: 0.5 mm Length of each cut: 100 mm Tool: HSS (side tool), Machine used: NH22 (HMT)	0.025 0.037	0.025 0.015

Table 2

Hot tensile test:

The ductility is measured by calculating percentage of reduction in area (%RA) of cross-section of the specimen at the position of fracture after the tensile test. If the cross-sectional area at fracture is small, %RA will be more. This means ductility is better and the material can sustain more amount of deformation. However, if the decrease in cross sectional area is small, then %RA becomes less and hence the ductility is low. So, the material can sustain less deformation before the formation of cracks. The ductility of steel generally varies with temperature, and there is a temperature range (relevant to casting temperatures) in which the ductility becomes very low. Thus, if the steel is deformed at a temperature in this range, there is a possibility of crack formation. The hot ductility test has been performed by employing a Gleeble machine. Both the conventional free cutting steel having lead as the additive and the free cutting steel having chromium (Cr) were subjected to hot ductility test. The hot ductility test involves reheating the steel to a solutionizing temperature followed by cooling. Then, a tensile testing is carried out when a test temperature is achieved.

The samples for hot tensile are cut into smaller pieces from the forged samples and specimens of cylindrical shape were machined from these pieces of the steel forged samples. In order to measure the temperature during the hot tensile tests at Gleeble machine, Pt-Pt/Rh thermocouple was spot

welded at the center of the specimens. The tensile testing of both the conventional free cutting steel having lead as the additive and the free cutting steel having chromium (Cr) [also referred to as specimen] at different temperatures in the range of 750–1250°C has been carried out. The maximum temperature of 1350°C has been chosen in order to ensure larger grain size and dissolution of all precipitates. The cooling is continued to test temperature at which the hot tensile tests of the specimens were carried out. The crosshead speed maintained has been 1.25 mm/min, which is equivalent to strain rate of 0.002083333, approximately assuming the deformation in the tensile test is concentrated over a length of 10 mm around the center of the specimen. The strain rate experienced by surface of the steel has been calculated using the following mathematical relationships.

$\varepsilon = t/2R$, where ε is surface strain due to bending, t is thickness of the steel and R is bending radius.
$\varepsilon^* = \varepsilon(V/L)$, where ε^* is the strain rate, V is the casting speed and L is the gauge length, which is assumed to be equal to thickness of the steel.

In the experiment, the diameters of the specimens before and after the test (at the position of the fracture) has been measured. The ductility is measured in terms of reduction in area (%RA). For fractography study, samples have been cut from the fractured specimens and then the fracture surfaces has been observed in a scanning electron microscope.

Referring now to **Fig. 7**, which illustrates the %RA values which are plotted against testing temperature during hot tensile test conducted using the Gleeble machine.

The hot ductility curves which have been generated by plotting %RA against different test temperatures for both the conventional free cutting steel having lead as the additive and the free cutting steel having chromium (Cr) are shown in **Fig. 7**. A ductility channel is observed for both the steels in the curves. The position and the width of the channels are varying for both the conventional free cutting steel having lead as the additive and the free cutting steel having chromium (Cr). As a comparison, the free cutting steel having chromium (Cr), has a maximum %RA value at the temperature range of 850-950°C, although it has lower Mn/S ratio. The higher %RA value is recorded to be better than the conventional free cutting steel having lead as the additive, which indicates the better hot ductility behavior of the free cutting steel having chromium

(Cr). Further, higher side of the hot ductility (%RA) value will be taken as consideration for straightening and below this value, straightening is not advised. Hence, the free cutting steel having chromium (Cr) is less prone to cracking during casting and rolling than the conventional free cutting steel having lead as the additive.

It should be understood that the experiments are carried out for particular compositions of the free cutting steel and the results brought out in the optical micrographs, graph, tables should not be construed as a limitation to the present disclosure as it could be varied based on composition and testing techniques and methods.

In an embodiment, the inclusion of Chromium (Cr) in the free cutting steel does not lead to harmful effects to the environment. Further, Chromium (Cr) is abundantly available and is economical.

In an embodiment, the free cutting steel having chromium (Cr) remains in solid solution during hot rolling of the steel which is suitable for manufacturing.

In an embodiment, the free cutting steel having chromium (Cr) may be significantly less costly compared to the conventional free cutting steel having lead additive.

In an embodiment, the free cutting steel having chromium (Cr) includes the required hot-ductility property to avoid cracking during casting and hot-rolling. In an embodiment, the composition and method described aid in reducing the amount of additive elements to minimize alloy cost.

It should be imperative that the composition and the method and any other elements described in the above detailed description should not be considered as a limitation with respect to the figures. Rather, variation to such composition and the method should be considered within the scope of the detailed description.

Equivalents:

With respect to the use of substantially any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations may be expressly set forth herein for sake of clarity.

It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as "open" terms (e.g., the term "including" should be interpreted as "including but not limited to," the term "having" should be interpreted as "having at least," the term "includes" should be interpreted as "includes but is not limited to," etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases "at least one" and "one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to inventions containing only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., "a" and/or "an" should typically be interpreted to mean "at least one" or "one or more"); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation *is* explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean *at least* the recited number (e.g., the bare recitation of "two recitations," without other modifiers, typically means *at least* two recitations, or *two or more* recitations). Furthermore, in those instances where a convention analogous to "at least one of A, B, and C, etc." is used, in general such a process intended in the sense one having skill in the art would understand the convention (e.g., "a method having at least one of A, B, and C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to "at least one of A, B, or C, etc." is used, in general such a process is intended in the sense one having skill in the art would understand the convention (e.g., "a method having at least one of A, B, or C" would include but not be limited to method that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that virtually any disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including

one of the terms, either of the terms, or both terms. For example, the phrase “A or B” will be understood to include the possibilities of “A” or “B” or “A and B.”

In addition, where features or aspects of the disclosure are described in terms of Markush groups, those skilled in the art will recognize that the disclosure is also thereby described in terms of any individual member or subgroup of members of the Markush group.

While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope being indicated by the following claims.

Referral Numerals:

Reference Number	Description
101-103	Flow chart blocks
101	Casting stage
102	Cooling stage
103	Metal working stage

We Claim:

1. A free cutting steel, comprising:

an alloy composition in weight (wt%) percentage of:

carbon (C) at about 0.07% to about 0.09%,

manganese (Mn) at about 0.5% to about 0.6%,

silicon (Si) up-to 0.05%,

phosphorus (P) at about 0.04% to about 0.09%,

sulphur (S) at about 0.38% to about 0.45%,

chromium (Cr) at about 0.7% to about 0.9%,

nitrogen (N) up-to 60ppm,

oxygen (O) up-to 0.012%, and

the balance being Iron (Fe) optionally along with incidental elements;

wherein, the free cutting steel comprises ferrite and pearlite microstructure.

2. The free cutting steel as claimed in claim 1, wherein the sulphur (S) and chromium (Cr) in the alloy composition expands crystallization temperature ensuing crystallization by monotectic reaction.

3. The free cutting steel as claimed in claim 1, wherein inclusion of at least one of the chromium (Cr) and manganese (Mn) in the alloy composition forms elongated shape sulphide inclusions in the ferrite and pearlite microstructure.

4. The free cutting steel as claimed in claim 1, wherein the free cutting steel exhibits hardness of about 146 HV to about 159 HV.

5. The free cutting steel as claimed in claim 1, wherein the microstructure of the free cutting steel is represented by, in area%, ferrite microstructure in the range of about 90% to about 95% and pearlite microstructure in the range of about 5% to about 10%.

6. The free cutting steel as claimed in claim 1, wherein the microstructure of the free cutting steel exhibits grain size in the range of about 10 µm to about 15 µm.

7. The free cutting steel as claimed in claim 1, wherein the free cutting steel is structured to have substantially large solidus temperature resulting in large sulphide inclusions

8. A method for manufacturing a free cutting steel, the method comprising:

casting a steel slab, comprising an alloy composition in weight percentage (wt%) of:

carbon (C) at about 0.07% to about 0.09%,

manganese (Mn) at about 0.5% to about 0.6%,

silicon (Si) up-to 0.05%,

phosphorus (P) at about 0.04% to about 0.09%,

sulphur (S) at about 0.38% to about 0.45%,

chromium (Cr) at about 0.7% to about 0.9%,

nitrogen (N) up-to 60ppm,

oxygen (O) up-to 0.012%, and

the balance being Iron (Fe) optionally along with incidental elements;

cooling, the casted steel to ambient temperature; and

subjecting the casted steel to a metal working process to from a free cutting steel;

wherein, the free cutting steel comprises ferrite and pearlite microstructure

wherein inclusion of at least one of the chromium (Cr) and manganese (Mn) in the alloy composition forms elongated shape sulphide inclusions in the ferrite and pearlite microstructure.

9. The method as claimed in claim 8, wherein the sulphur (S) and chromium (Cr) in the alloy composition expands crystallization temperature ensuing crystallization by monotectic reaction.

10. The method as claimed in claim 8, wherein the metal working process is a wire rolling process.

11. The method as claimed in claim 8, wherein the microstructure of the free cutting steel is represented by, in area%, ferrite microstructure in the range of about 90% to about 95% and pearlite microstructure in the range of about 5% to about 10%.

12. The method as claimed in claim 8, wherein the free cutting steel exhibits hardness of about 146 HV to about 159 HV.

13. The method as claimed in claim 8, wherein the free cutting steel exhibits hardness of about 124 HV to about 135 HV.

14. The method as claimed in claim 8, wherein the microstructure of the free cutting steel exhibits grain size in the range of about 10 µm to about 15 µm.

15. A wire rod comprising a free cutting steel as claimed in claim 1.

16. Machinability property was evaluated in terms of

a) tool wear (0.015-0.025 mm),
b) Chip size: similar to standard product AISI12L14,
c) Surface finish: as good as AISI12L14 grade.

Dated this 04th of February 2022

GOPINATH A S
IN/PA – 1852
OF K&S PARTNERS
AGENT OF THE APPLICANT(S)

“A FREE CUTTING STEEL AND A METHOD OF MANUFACTURING THEREOF”

ABSTRACT

Present disclosure discloses a free cutting steel and a method for manufacturing the free cutting steel. The free cutting steel includes an alloy composition in weight (wt%) percentage of carbon (C) at about 0.07% to about 0.09%, manganese (Mn) at about 0.5% to about 0.6%, silicon (Si) up-to 0.05%, phosphorus (P) at about 0.04% to about 0.09%, sulphur (S) at about 0.38% to about 0.45%, chromium (Cr) at about 0.7% to about 0.9%, nitrogen (N) up-to 60ppm, oxygen (O) up-to 0.012%, and the balance being Iron (Fe) optionally along with incidental elements. The free cutting steel with said alloy composition includes ferrite and pearlite microstructure. The addition of chromium aids in improving the machinability of the free cutting steel without being an environmental hazard.

Fig. 1 is the representative figure.