Lecture 27 Clean Steel

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Key words: Inclusion in steel, inclusion engineering, clean steel

What is clean steel?

Clan steel refers to steel which is free from inclusions. Inclusions are non metallic particles embedded in the steel matrix. Practically it is not possible to produce steel without any inclusion. Therefore we can talk about cleaner steel. Which steel is clean would depend on the applications. In this connection it is important to know that there is a limiting size below which inclusion does not affect mechanical property. Table lists some applications which can tolerate some minimum inclusions size:

Steel product	Allowed impurity in ppm	Allowed size(μm)
Automotive and deep drawing sheet	C<30, N<30	100
Line pipes	S<30, N<50, TO<30	100
Bearings	TO<10	15
Tire cord	H<2N<40, TO<15	10
Heavy plate steels	H<2 N+30 to 40, TO<20	13
Wires	N<40, TO<15	20
Drawn and ironed cans	C<30, N<40, TO<20	20

Types of inclusions:

Inclusions are chemical compounds of metals like (Fe, Mn, Al, Si, Ca etc) with non metals (O, S, N, C, H). Different types are:

- Oxides: $FeO, Al_2O_3, SiO_2, MnO, Al_2O_3.SiO_2, FeO.Al_2O_3, MgO.Al_2O_3, MnO.SiO_2$
- Sulphides: $FeS, CaS, MnS, MgS, Ce_2S_3$, Nitirides: TiN, AlN, VN, BN etc.

- Oxysulphides: $MnS.MnO, Al_2O_3.CaS$, etc
- Carbonitrides: Titanium/ vanadium/Niobium carbonitirides, etc
- Phosphides: Fe_3P, Fe_2P, Mn_5P_2

By mineralogical content, oxygen inclusions are classified:

- Free oxides - $FeO, MnO, Cr_2O_3, SiO_2(quartz)Al_2O_3$ (corundum) and other;
- Spinels – Ferrites, chromites and aluminates.
- Silicates- SiO_2 with a mixture of iron, manganese, chromium, aluminum and tungsten oxides and also crystalline silicates.

By stability, non –metallic inclusions are rather stable or unstable. Unstable inclusions are iron and manganese sulfides and also some free oxides.

Morphology

Globular shape is desirable. Certain inclusions like MnS, oxysulphides, iron aluminates and silicates are globular.

Platelet shape: undesirable. Al deoxidized steels contain MnS in the form of thin films located along the grain boundaries.

Polyhedral inclusions are not very harmful.

Size of inclusions

There are micro inclusions($size\ 1-100\mu m$) and macro-inclusions (size greater than$100\mu m)$. Macro inclusions are harmful. Micro inclusions are beneficial as they restrict grain growth, increase yield strength and hardness. Micro- inclusions act as nuclei for precipitation of carbides and nitrides. Macro-inclusions must be removed. Micro inclusions can be used to enhance strengthening by dispersing them uniformly in the matrix.

Properties of inclusions:

i) Thermal expansion.

An inclusion is a mismatch with the steel matrix. There are inclusions like $MnS, Ca\ S$, etc. which have thermal expansion greater than steel matrix. On heating steel with these types of inclusions voids or parting of the matrix can occur. The void can act as cracks.

On the other hand Al_2O_3, SiO_2 and $CaO.Al_2O_3$, etc inclusions have thermal expansion smaller than steel matrix. On heating steels with these type of inclusions internal stresses of thermal origin can develop.

Density and melting point

ii) Density and melting point		
Composition of inclusions	Melting point(^{0}C)	Density at 20^{0}C(g/cm^3)
Ferrous oxides (FeO)	1369	5.8
Manganous oxides (MnO)	1785	5.5
Silica	1710	2.2-2.6
Alumina (Al_2 O_3)	2050	4.0
Chrome oxide Cr2	2280	5.0
Titanium oxide, TiO_2	1825	4.2
Zirconium oxide, ZrO_2	2700	5.75
Iron silicate, $(FeO)_2SiO_2$	1205	4.35
Iron sulphide, FeS	988	4.6
Manganese sulphide, MnS	1620	4.04
Magnesia, MgO	2800	3.58

Inclusions like $\mathrm{MgO}, \mathrm{Al_2O_3}, \mathrm{TiO_2}$ are solid at steelmaking temperature.

iii) Plastic deformability

The plastic deformability of an inclusion will govern any change in its shape under the action of external forces and will determine the amplitude of stress concentration. Brittle inclusions are dangerous as they may crack and cause fracture of the component under the application of external force. The majority of inclusions belong to pseudo-ternary system: $\mathrm{CaO} - \mathrm{SiO_2} - \mathrm{Al_2O_3}, \mathrm{MgO} - \mathrm{SiO_2}, -\mathrm{Al_2O_3}\ \mathrm{CaO} - \mathrm{SiO_2} - \mathrm{Cr_2O_3}$ etc. Sulphide inclusions are mainly MnS. Other elements like Ti, Zr, rare earths, Nb, V etc. usually appear as solid solutions in existing inclusion phases. The following classification of inclusions according to kieslling is useful to the metallographers to determine type of inclusions: According to Kieslling

(i) Calcium aluminates and $\mathrm{Al_2O_3}$ inclusions in steel are undeformable at temperatures of interest in steelmaking.

(ii) Spinel type double oxides $\mathrm{AOB_2O_3}$ (where A is Ca, Fe(l), Mg and Mn,and B is Al,(Cr etc) are deformable at temperatures greater than1200°C .

(iii) Silicates are deformable at higher temperature range. The extent of deformation depends on their chemical compositions. Silicates are not deformable at room temperature.

(iv) $\mathrm{FeO}, \mathrm{MnO}$ and $\mathrm{(Fe, Mn)O}$ are plastic at room temperature but gradually lose plasticity above 400°C.

(v) MnS which is highly deformable at 1000°C temperature but becomes slightly less deformable above 1000°C .

(vi) Pure silica is not deformable up to 1300°C .

Inclusion assessment

Inclusion counts are performed to assess their shape, quantity and distribution to assess about the cleanliness of steel.

The routine plant procedure employes the microscopic method. From the shape of the inclusion and knowledge of the steelmaking process in a plant, it is inferred to whether it is silica/ silicate, aluminate or sulphide inclusion

Electron probe micro analyzer enables to determine the chemical composition of individual inclusions.

The energy dispersive x-ray analysis (EDX) attachment for SEM allows quantitative chemical analysis of inclusion as well as quantitative mapping of distribution of various elements in and around the inclusions.

Quantimet has an optical microscope fitted with video screen and associated microprocessor-based instrumentation. It can scan the specimen very quickly and provide a variety of information such as inclusion size, distribution, number, volume fraction, etc.

Total oxide inclusion content of steel can be determined from the analysis of oxygen by sampling and the use of vacuum /inert gas fusion apparatus.

Radioactive tracers can identify the origin of inclusion distributions, etc.

The readers can see the references given at the end of lecture 29 for the details