Effect of Cooling Rate on Mechanical Properties of ASTM Grade Steel

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Abstract . The objective of the present research is to produce cryogenically treated low carbon low alloy steel which has extreme properties for that composition like high tensile strength, high hardness and wear resistance. The cryogenic treatment is given to steel during solidification, which introduces severe chilling effect in steel. The under cooling of the melt during solidification increases the number of nuclei and thereby enhance the properties of steel. Chills of different thermal conductivity are used to get chilled steel for comparison purpose. It was found from literature review that, so for no work has been done on cryogenically treated steel during solidification. Hence, the present investigation is undertaken to fill the void.

Keywords : Chilled steel, cooling rate, Microstructure, Pearlite

1 Introduction

Steel with very low carbon content is generally not responsive for heat treatment and has nearly the same properties as iron. It can be easily formed as they are quite softer. As the carbon content increases becomes stronger and harder by gradually losing its ductility. The properties of iron and steels are linked to the chemical composition, processing path and resulting microstructure of the material. The metal alloys solidify over arrange of temperature. Solidification behavior depends on parameters such as growth rate, temperature gradient and alloy constituents. Temperature gradient and growth rate influence the solidification morphology and solidification substructure respectively. Growth rate or solidification rate is the rate of advance of the solid/liquid interface into the liquid. [1] The rate of movement of solidification front determines solute distribution during solidification, scale of solidification substructure and the growth undercooling. Rapid solidification (faster movement of solid/liquid interface) minimizes the tendency of segregation of elements temperature gradients both in solid and liquid are important [2].

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2 Methodology

Preparation of wooden pattern for four cavities mold and providing gating systems like location of risers, runners and gates etc. Preparation of end chills metallic, non-metallic and metallic with water cooled one each. Preparation of sand mold with CO2 process by providing end chills. Preheating and setting the mold sets.Pouring the prepared liquid melt by using induction furnace into the molds.Removing the cast blocks from the molds by knocking process. Debating cast blocks by removing risers, runners, gated, fins etc. by fettling process. Shot blasting process to remove sand particles adhered on the surface of castings. Preparations of test samples as per ASTM standards from the cast blocks.Conduction of tensile and hardness tests to find mechanical properties. Tabulation and analysis of test results[3] [4].

3 Experimental Procedures

Preparation of Mold: Wooden pattern was used to prepares and mold with CO2 process and four activities were created in a mold. In the four cavities of the mold, copper chill, silicon carbide chill and cold water circulated copper chill was provided one in each cavity and a cavity without a chill. Two risers are provided in the gating system at suitable locations to get sound cast specimens and sufficient care has been taken in the gating system to avoid defects in castings. The end chills used were fabricated to required size and set in CO2 molds (AFSstandardofsize115*75*25mm) with arrangements made to circulate chilled water. Molding sand mixed with sodium silicate (silica gel) and water at suitable proportions and mixed by a Muller. Four mold sets were prepared and each mold having four cavities were applied with zircon fluid for smoothness of the cavities and to avoid fusing of sand, then molds were preheated by torch burner and kept ready for pouring liquid melt.

Table 1. Chemical Composition of the ASTM grade steel

Alloy Designation	C	Si	Mn	P	S	Cr	Mo	Ni	Cu
A-Mold-1)	0.23	0.45	0.82	<0.008	<0.008	0.06	0.05	0.02	0.008
B-(Mold-2)	0.23	0.45	0.82	<0.008	<0.008	0.06	0.05	0.02	0.71
C-(Mold-3)	0.23	0.45	0.82	<0.008	<0.008	0.06	0.05	0.02	1.45
D-(Mold-4)	0.23	0.45	0.82	<0.008	<0.008	0.06	0.05	0.02	1.90

Base Material: The chemical composition of the base alloy (ASTM GradeSteel) used in this investigation and the compositions of chilled ASTM Grade steel cast separately was analyzed using an emission spectrometer.Pure carbon in the form of shell coke was used to bring the carbon content in the steel to required percentage.

Molding Process: One metallic (copper), one non-metallic (silicon carbide) and one chilled water circulated chills were used in the present research. Chills use dare of size 25mmx25mmin cross-section and 150mm in length. All the chills were made of having thickness of 25 mm. Chills of different material were placed on the match plate pattern at desired location in order to introduce chilling effect and to achieve directional solidification during solidification process and to get sound castings. Arrangements were made to circulate cold water through one copper chill.

ThemoldwaspreparedusingCO$_2$moldingprocess. The sand used for the process containa maximum moisture contentof0.25%andfreefromclay.The process is basically a hardening process for molds and cores. The principle of CO_2 moldingprocess is based on the fact that if CO_2gas is passed through a sand mix containing sodium silicate, the sand becomes strongly bonded as the sodium silicate becomes as if the necessary strength to the mold. Zircon sand coating (Trade name – Ceramal) was applied to mold to get good surface. The mold wasthendriedusinggastorch. thenmold halveswereclosedcarefully. Thegating system for casting (AFS standard) as well as the prepared mound is as shown in Figure2.

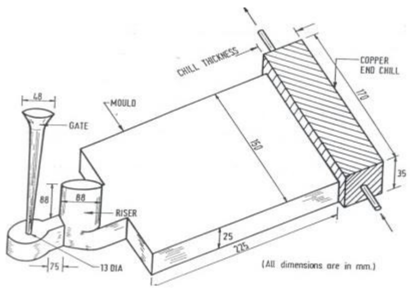

Fig.1.AFS Standard mould cavity along with an end chill.

Fig.2. Mold cavities with different end chills,

Melting and Pouring of liquid metal:

.The base metal composition of carbon, silicon, was melted using medium frequency induction furnace. The furnace was charged with steel scrap and melted in 150kg capacity induction furnace. Chemical composition was adjusted and maintained the steel having the composition of ASTM grade steel shown in table no1at the time of pouring.

Melting Process:

.Ferro-Chrome around 950 gmwas poured into the melt which may weighing approximately 80 kgsand stirredwell. The melt was super-heated to 1650 ºC and taken into a preheated ladle containing calcium silicide (which acts as deoxidizingagent)forpouring.Hottoppingcompoundwhich isa mixtureofsilica,aluminumoxide,ironoxideandcarbon willalsobepouredintothemoltenmetaltoretaintheheatin themelt.Finally, the treated molten metal from the preheated ladle wasdirectlypouredbymaintainingatemperatureof1620°C intothefirstmold withoutaddingcopperandchilledwater (5°C) circulation made through one of the chills(copper) while pouring the liquid metal into the mold.

4 Results and Discussions

4.1 Microstructural Analysis

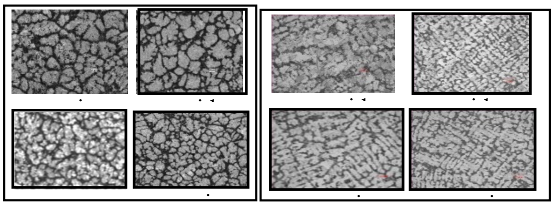

Fig.3. Effect of chilling on microstructure (a) (Mould-1) (b) Mould-2

Specimens were prepared for metallographic studies. Test samples are polished by emery paper in sequence with differentgradesfollowedbypolishingusingnylonclothand aluminapowderofsubmicronsizeanddiamondpaste.After polishing samples were etched with 2% Nitalsolution and rinsed indistilledwatertoevolvegrainboundarieswhilethe microstructural features were examined under an optical microscope Nikon Microscope LV150 with Clemex Image Analyzer at X100 and X500 magnification and the micrograph presented. Equipment used is Nikon Microscope LV150 with ClemexImageAnalyzer.

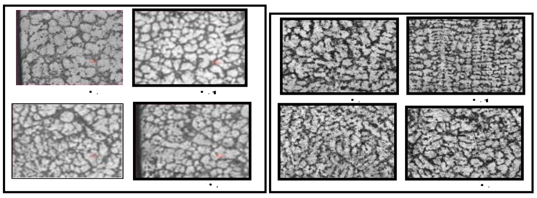

Fig.4. Effect of chilling on microstructure (Mould-3) (c) Mould-4

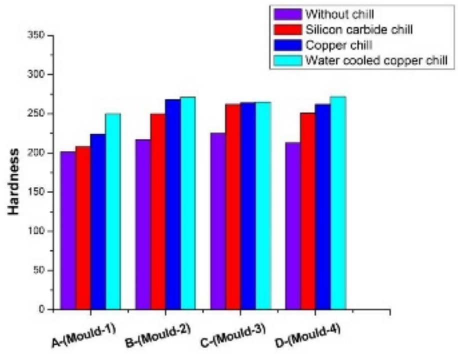

Fig.5. Tensile strengths and hardness of un-chilled and chilled specimens

Microstructural analysis reveals that the Microstructure consists of ferrite grains with pearlitic grain boundaries observed in cast specimens without using chills. The cast samples produced using SiCchills reveals that the microstructureconsistsofferritegrainsofdendriticgrowth with pearlitic grain boundaries. But the cast specimens produced using copper chills consists of feathery mass of cementitanddendriticgrowthofferritewithpearliticgrain boundariesbecauseofbetterthermalconductivityatthechill end.Further,themicrostructureconsistsofacicularstructure of cementite and dendritic growth of ferrite with pearlitic grain boundaries observed in cast specimens producedwith water cooled copper chills.

4.2 Hardness Test

TheVicker'shardnessnumber(HV)ofthetestsampleswere measured using HWMMT-X7-microhardness tester. The values reported are the average of three repetitions on the samesample.The experimental results on hardness test for all test specimens conducted and tabulated in table 2. It has been observedthatanincreaseinhardnessinthetestspecimens used water cooled copper chills because of effective directional solidification and more chilling effect causeformationofcarbideprecipitation and justified the investigator [3]. The Noticeableimprovement inhardness is alsoobservedintestspecimens producedusing copperchills.Thetestspecimenscastedwere shown no considerable improvement in its hardness becauseoftheinfluenceofprogressivesolidificationcaused by the absence ofchills.

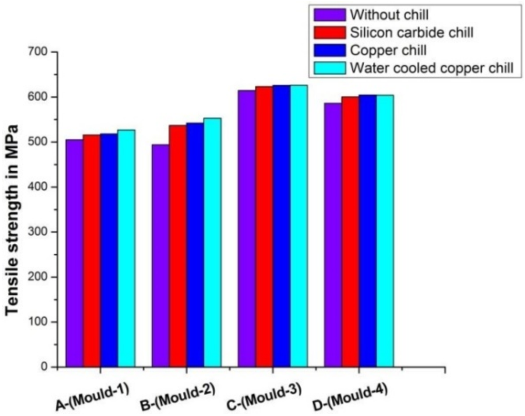

Table 2. Results of hardness test of various test samples

Alloy Designa-tions	Without chill	Silicon carbide chill	Copper chill	Water cooled copper-chill	Copper composition
A-(Mould-1)	201	208	224	250	0.008
B-(Mould-2)	217	250	268	271	0.71
C-(Mould-3)	225	262	264	265	1.45
D-(Mould-4)	213	251	262	272	1.90

4.3 Strength Test

Tensile tests were conducted at room temperature on computerized Universal testing machine of 60t capacityinaloadrangeof0–600KN.Threetestspecimens were taken from the chill end and prepared as per ASTM standards.Thealloy composition and also it is observed that test specimenscastwithwatercooledcopperchills exhibit the higherstrength due to higher chilling effect during solidification and it supports with report of the author [3]. Further,castspecimenswith copperchills show relatively higherstrengthwithrespecttotestsamplesproducedwith silicon carbidechills.Thetensilestrengthofthecastspecimensproduced without using chills shows lesser strength compared to other test samples.Thisisbecauseofpoorthermalconductivityand influenceofprogressivesolidificationfromallsides ofthe castspecimens.

Table 3. Results of UTS test of various test samples

Alloy Designa-tion	Without chill	Silicon arbide chill	Copper chill	Water cooled cu chill	Copper composition
A-(Mold-1)	504.96	515.7	518.03	526.75	0.008
B-(Mold-2)	494.08	536.9	542.15	552.92	0.71
C-(Mold-3)	614.22	623.3	626.02	626.3	1.45
D-(Mold-4)	586.06	600.1	604.57	604.17	1.90

5 Conclusion

The rate of cooling of a solidifying metal controls the structureofthemetal-whichinturnpropertiesofthematerial. Improvedmechanicalpropertiesobservedin-castspecimenproducedusingwatercooledcopperchillwhichcausesmore chilling effect duringsolidification.Thehigherhardnessandhighertensilestrengthobservedin cast spec-imens used water cooled copper chills. Lower mechanicalpropertiesobservedin-castspecimenproduced without using chills because of these cast specimens Figure5 Tensile strength of un-chilled and chilled specimensinfluenced by progressive solidification from all the directions.Chillingeffectduringsolidificationinfluenceson improvement in mechanicalproperties.

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