Steel Quality Role of Secondary Refining and Continuous Casting
Dr. Santanu Kr Ray
Department of Mechanical Engineering
Indian Institute of Technology, Madras

Module – 07
Lecture – 37
Role of Chemistry on Bulging or Depression Tendency: Part II

In the last session I had talked about the bulging or depression behaviour based on solidification characteristics, for the different range of you know chemistry for the plane carbon and the alloy steels and also for the stainless steels.

(Refer Slide Time: 00:33)

Bulging or Depression Behaviour based on Solidification Characteristics

	0.02 – 0.05 % C_{eq}	Peritectic ~ 0.1 % C_{eq}	0.2 – 0.4 % C_{eq}	> 0.5 % C_{eq}
Solidification Mode	Entirely δ	δ till f_s ~ 0.75 δ + γ at f_s : 0.8 – 1.0	δ till f_s ~ 0.3 δ + γ at f_s : 0.3 – 0.5	Entirely γ
Solid Shell	Thick but weak	Thick and strong	Thin	Thin but strong
Mushy Zone	Narrow	Narrow	Deep	Deep
δ → γ around Solidus	---	High	---	---
Mould Sticking	High	---	High	High
Bulging	High	---	High	High
Depression	---	High	---	---

So, what I had mentioned there was for the different carbon concentrations or carbon or carbon equivalent concentrations what will be the solidification mode what is the solid shell thick what is the strain how what is the mushy zone if the solid shell is thick mushy zone will be narrow and if solid shell is thin mushy zone will be you know quite wide deep. So, and the wave above the delta to gamma transformation is taking place where the near solidus, because near solidus is a real point of (Refer Time: 01:09) because that is the temperature is invert it is brittle. So, there is a possibility of crack formation.

And what is the behaviour of sticking or a bulging based on this. So, there I had mentioned that for very low carbon and very high carbon; that means, except for the peritectic chemistry range of 0.1 percent carbon I am talking the temperature that the chemistry range it is not exactly 0.1 it maybe 0.07 to 0.17. So, this particular chemistry range we have a depression tendency I have told you why and for lower carbon range compared to that and higher carbon range compared to that we have taking in bulging tendency.

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Bulging or Depression Behaviour based on Solidification Characteristics

	AISI 430	301	304	316	310 S
Solidification Mode	Entirely δ	Entirely δ	δ till $f_s \sim 0.75$ $\delta + \gamma$ at f_s : 0.8 - 1.0	δ till $f_s \sim 0.3$ $\delta + \gamma$ at f_s : 0.4 – 0.8	Entirely γ
Solid Shell	Thick but weak	Thick	Thick and strong	Moderate	Thin but strong
Mushy Zone	Thin	Thin	Thin	Moderate	Thick
$\delta \rightarrow \gamma$ around Solidus	---	Minor	High	Moderate	---
Mould Sticking	High	---	---	---	High
Bulging	High	---	---	---	High
Depression	---	Minor	High	Moderate	Minor

Similarly, for stainless steel I have explained in the last session for 304 which has a nickel equivalent of chromium equivalent around 0.55 slightly more than 0.55, we have a high depression tendency why because this delta to gamma is taking place towards the end of the solidus delta to gamma around solidus is relatively high. Because of this depression tendency is relatively high because it is taking place in the brittle temperature region. So, chances of depression will be more surface will be rough, but for other chemistry; that means, the other stainless steel grates which have either very low nickel equivalent (Refer Time: 02:46) that means, for a the ferritic grades or the totally of austenitic grades by solidification is through entirely through austenitic mould.

What is happening is we have sticking out bulging tendency of course, for different reason for very high nickel equivalent by chromium equivalent similar to the behavior of very high carbon more than 0.5 percent carbon equivalent, solidification is entirely through gamma micro solidification is very high shell thickness during solidification is quite narrow very thin, and the mushy zone is quite deep you know its thick. So, because of that the sticking and bulging term is quite high, because the thin shell solid shell cannot with stand ferrostatic pressure. But for the other extreme chemistry region; that means, when nickel equivalent and chromium equivalent is very low is like very low carbon for the carbon grades, for 430 say here I say 430 nickel equivalent and chromium is very. So, solidification is entirely to delta the delta to gamma takes place quite low temperature compared to solidification completion. So, the solid shell is though it is thick because micro solidification is less, but it is week.

Which means why it is week it has low strain why? Because it is delta not only during solidification even after solidification completion also it continues to be delta for quite some time for quite some temperature. So, this weak solid shell again can may cause taking and below the mould bulging. So, these are the tendency for different chemistry rangers.

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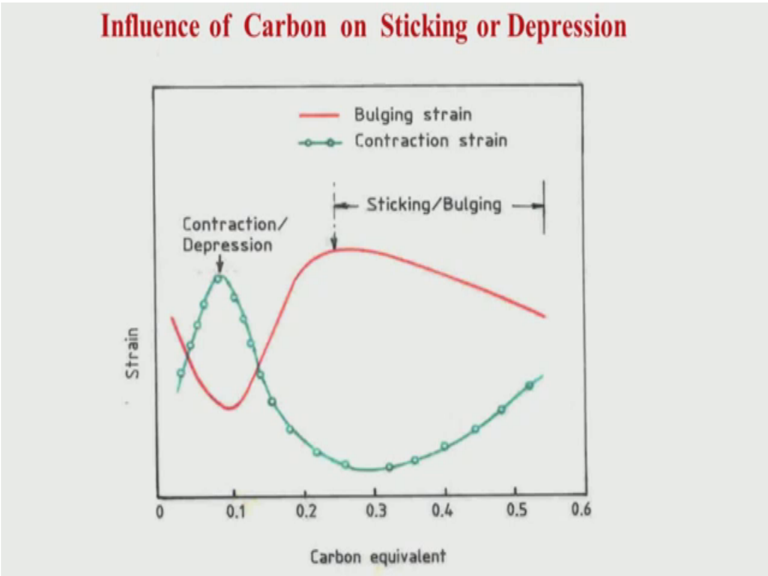

Now, the same behaviour can be shown pictorially based on the distribution of carbon equivalent.

So, first I will show you what is the influence of carbon on sticking or depression I have told you I have given you certain examples of different you know carbon contents, grades for having different carbonyl carbon equivalent. Now let us see for different carbonic equivalent how the two strains are varying, I have told you that there are two opposing strains one is a bulging strain or the sticking strain another is the contraction strain.

So, I have told you around 0.1 percent carbon what is happening? This bulging strain is relatively less and the contraction or depression strain is relatively high, why this is relatively high, why contraction? And depression is single because of the delta to gamma transformation taking place towards the end of solidification near the solidus temperature that is why this is relatively high compared to other carbon equivalents and incidentally in this particular you know composition in this particular chemistry, you know the contractions strain is relatively high, but the bulging strain is relatively low.

Why it is relatively low? Because you have a thick shell and also towards the end of the solidification delta 2 gamma transformation is taking place. So, it has become already austenite. So, the shell is thick and strong. So, it can withstand ferrostatic pressure. So, the tendency will be more of contraction and depression rather than sticking or bulging. So, at 0.1 this is contraction or depression is predominanting and for high carbonic equivalents around 0.25 and above.

The sticking and bulging strains are relatively more why because a micro solidification because of austenitic solidification predominating and increasing relatively, we have very thin shell because of that it cannot withstand the ferrostatic pressure ferrostatic strain. So, the sticking and bulging strain is relatively more compared to the contractions strain. So, therefore, the sticking and bulging behaviour will predominant at relatively high carbon, same thing is happening for very low carbon you see it is increasing and the contraction and depression strain is decreasing.

So, both at very low carbon that was 0.02, 0.03, 0.04 it is relatively sticking and bulging strain is more and around say above 0.2 it is relatively more sticking and bulging. The reason maybe different here the reason is very thin shell here the reason is very weak shell solid shell solid shell is weak here, because it totaled in delta here it totally austenitic. So, the shell is strong, but because of high micro segregation it is thin and because even the strain sticking or sticking strain or the bulging strain is inversely proportional to the square of the thickness of the shell.

So, that the thickness of the shell is narrow it is thin then it cannot withstand a ferrostatic pressure. So, the sticking and bulging strain is relatively high similar behavoiur you will see for stainless steel.

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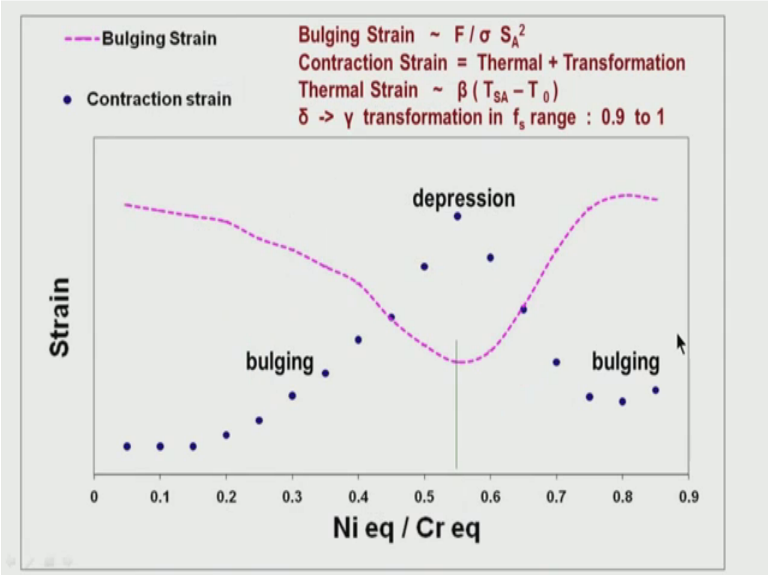

So, there it was for plane carbon and carbon equivalent it means the carbon or the carbon equivalent, which is the deciding factor for chemistry for stainless steel as I have told you earlier it is the nickel equivalent by chromium equivalent a ratio of that, which is going to play a crucial role which indicates how the chemistry is varying how the solidification mode will change and consequently what will be the solidification characteristics what will be the bulging tendency or you now depression tendency.

So, let us see here what is happening you see at around 0.55 nickel equivalent and chromium equivalent, similar to the situation of 0.1 carbon equivalent here it is 0.55 nickel equivalent by chromium equivalent. The depression strain the contraction strain this one contraction strain this dot area this points circles, they are relatively high, why it is high? Because this delta to gamma transformation is taking place mostly in the crucial brittle temperature zone of 0.921 and because of that you know lot of strain is generated and because of that lot of contraction strain is generated and because of that there is a depression tendency.

But for very low nickel equivalent by chromium equivalent or for very high nickel equivalent by chromium equivalent, this bulging strain is much more compared to the contraction strain. For very low nickel equivalent chromium equivalent delta ferrite mode of you know solidification is predominating, and delta ferrite is stable at quite what temperature even after solidification is complete. So, this weak delta ferrite shells solid shell is the cause of high bulging strain because it is soft it cannot withstand the ferrostatic strain. So, it is ferrostatic force which is relatively high and the contraction strain is quite low.

At high nickel equivalent chromium equivalent what is happening is, it is austenitic solidification because of austenitic solidification might micro segregation is quite high because of that solid shell is thin and because of that it cannot withstand ferrostatic pressure or force so, here also the contraction other than that. Yeah the bulging strain is relatively high contraction strain is low. So, the behaviour here also is bulging. So, only at nickel equivalent chromium equivalent of around 0.55, we have depression tendency very predominant depression tendency, this region of the chemistry.

Incidentally 304 the common stainless steel belongs to this chemistry range nickel equivalent chromium equivalent around 0.56, 0.57. So, this is the chemistry where we have lot of depression surface depression. And if you have surface depression rough surface because of that the heat transfer is affected and near the surface, and we have course dendrites on the near the surface, unlike you know other grades were we have relatively final grains either the surface because the heat transfer is quite high.

Here you know this depression formation is creating air gap between surface of the solid shell and the mould and that affects the heat transfer and that is why you have lot of the this wherever there is depression beyond the depression, you know beneath the depression we have coarse grains coarse dendrites which is again not desirable the crack formation again is becomes easier if you have a coarse grain structure. So, we have to keep in mind that because of nickel equivalent by chromium equivalent, at what nickel equivalent chromium equivalent there is a depression tendency and at what chemistry we have bulging tendency.

So, if you understand this then accordingly we can select the casting parameters, we know the solidification behaviour we know the intrinsic characteristic for the different chemistry. So, accordingly we can decide what should be the heat transfer in the mould, what will be the intensity of secondary cooling because if there is bulging; that means, you have to use relatively higher intensity of secondary cooling so that the shell becomes relatively thick more thick and the temperature of the shell as you are using more what I means temperature of the shell will come down relatively faster.

So, the strength of the shell also will increase and delta to gamma transformation will be enhanced. So, if you have austenite the strength will be relatively more. So, to increase the strength of the shell you need more amount of cooling is necessary secondary cooling. So, depending on the solidification characteristic of a particular alloy, we can decide what should be the casting parameters. We can decide how the different powder will be used powder means mould powder will be used because that mould powder after it gets moultant say that is it decides the thickness of the relative thickness of the solid (Refer Time: 15:40) liquid you know my region of the moulds lag between I have mentioned this earlier, between the mould surface and the solid shell surface.

What is the relative thickness of the mould slag, solid slag and the liquid slag, that determines what is the heat transfer characteristics, that determines how it can resist you know sticking. So, for sticking you have one type of powder because the sticking has to be resisted, but for depression you have other type of powder where the heat transfer has to be relatively taken care of, because you have heat less heat transfer. So, heat transfer should not be high in that region.

So, these are all dependent things depending on the characteristic of the particular alloy, you design your casting parameters this is very important.