

An Investigation on Mold Powders Properties Consumed in Iran

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Abstract

This paper describes the work done between IUST and two Iranian steelworks to evaluate and review the performance of mould fluxes in current use for continuous casting. Calculations have been performed to compare actual values of powder consumption, viscosity and break temperature of the fluxes in current use with required values derived from published empirical rules for casting conditions. It has been found that there is, in general, poor agreement between actual and required values. The required viscosities of mould fluxes consumed in MC grades are 2.2 and 1.9 dPas while the measured values are 1.5 and 1.1 dPas, respectively indicating higher values. This situation is reverse in LC grades, and actual viscosities are lower than the measured values based on empirical rules. There is also a disagreement between the carbon content and break temperature of the current fluxes and required values resulting in the defects in produced slabs. These differences are more critical in MC grades.

This does not necessarily mean that fluxes are not working well but does imply that a review of mould flux performance is needed before the planned increases in production are implemented.

One steel company experienced problems with overflows of steel (bleeds) and with depressions in the surface of the slab. Possible reasons for the formation of these defects are proposed.

Keywords: Steel, Continuous-Casting, Mould Flux Properties.

Introduction

In this paper we examine the mould fluxes in current use at two steelworks and compare their properties with those based on empirical rules for optimum casting. The two steelworks are the Khouzestan Steel Company and the Mobarakeh Steel Company. The current production rates are 3.5 and 4.5 million tonne per annum, respectively, but both companies plan to expand production considerably in the near future.

The mould fluxes play a key part in the continuous casting process. The mould must successfully carry out all the following functions:

- (i) Prevent oxidation of the steel meniscus.
- (ii) Provide thermal insulation to prevent the steel meniscus from freezing.
- (iii) Lubricate the newly-formed shell.
- (iv) Control the (horizontal) heat transfer from shell to mould.
- (v) Absorb inclusions from the steel.

The mould flux is poured into the mould where it undergoes the following changes (Figure 1):

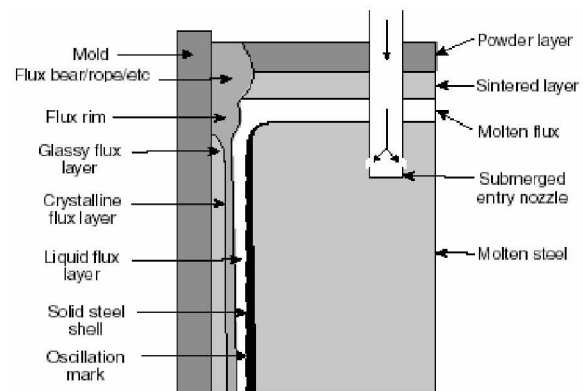


Fig. 1. Schematic drawing showing various flux layers formed in the mould.

1. the carbon particles combust with oxygen to form CO(g)
2. the mineral particles sinter and , eventually, form molten slag globules

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3. the globules are prevented from agglomerating by carbon (which is non-wetting to slag) particles.

4. The carbon particles react with O₂ (g) and eventually disappear at the point the mineral constituents form a molten slag pool.

Molten slag from the liquid pool is drawn into the shell/mould gap during the down-stroke of the mould and is rapidly quenched to form a slag film between the shell and the mould. The slag film contains a liquid layer (typically 0.1mm thick) and a glassy, solid layer (typically 2 mm thick). This glassy layer crystallises with time and results in the formation of an interfacial resistance at the Cu/slag interface. The lubrication supplied to the strand is determined by the thickness of the liquid layer, and the horizontal heat transfer from the shell is determined by (i) the thickness of the solid layer and (ii) the fraction of crystalline phase in the solid layer (which is also dependent on slag film thickness).

Wolf¹⁾ introduced the concept of optimal casting i.e. in which defects and problems like sticker breakouts were at a minimum suggesting that optimal casting conditions occurred when Equation 1 was satisfied:

$$\eta V_c^2 = 5 \pm 2 \text{ dPas (m min}^{-1}\text{)}^2 \quad (1)$$

where V_c=casting speed and η=flux viscosity (at 1300°C).

Ogibayashi²⁾ suggested an alternative relation for optimal casting:

$$\eta V_c = 2.5 \pm 1 \text{ dPas (m min}^{-1}\text{)} \quad (2)$$

Subsequently, Wolf³⁾ pointed out that optimal casting can be defined in terms of powder consumption. This parameter is usually measured on plant as Q_t in kg (flux) tonne (steel)⁻¹ and represents a measure of the cost of mould fluxes. However, it can be converted into Q_s (with units of kg (flux) m² (mould)) using equation 3

$$Q_s = 7.6 f^* Q_t / R \quad (3)$$

where 7.6=density of steel in tonne m⁻³, f*= fraction of flux forming slag, and R is the ratio of (surface area/volume) of the mould and =2(w+t)/ w.t , where w and t are the width and thickness of the mould in metres, respectively. The parameter, Q_s is a measure of the lubrication supplied to the shell and is related to the thickness of the liquid layer (d_l) of the slag film {Q_s= ρ(d_l) where ρ=density of the flux (=ca. 2600kgm⁻³). Frictional forces increase with distance from the corners and consequently more lubrication (or higher Q_s) must be supplied for larger mould cross-sections. The parameter, R, is a convenient way of representing the distance from the corners and the following empirical relation was obtained for the required powder consumption (Q_s^{req})⁴⁾.

$$Q_s^{req} = 2/R-5 \quad (4)$$

An alternative empirical relation⁵⁾ can be used

$$f^* Q_t = 0.48 \text{ kg tonne}^{-1} \quad (5)$$

The required powder consumption, Q_s^{req}, can be related to the required viscosity (η_s^{req}) of the flux through either Equn 6 or 7^{3,5)}.

$$Q_s^{req} = 0.55 / V_c (\eta_s^{req})^{0.5} \quad (6)$$

$$Q_s^{req} = 0.6 / V_c (\eta_s^{req}) \quad (7)$$

It has been shown⁶⁾ that the powder consumption is affected by other parameters in addition to casting speed and the flux viscosity; namely, the frequency, stroke length and solidification temperature of the flux, but their effects tend to be smaller. Several empirical relations have been reported involving various combinations of these variables, and these have been reviewed by Fox^{5,7)}.

In practice, the actual powder consumption (Q_s^{meas}) may be lower than the required value of (Q_s^{req}) due to (i) a low melting rate (a shallow slag pool) or (ii) partial blockage of the shell/mould channel by agglomerated inclusions e.g. Al₂O₃, TiN.

The melting rate (MR) is controlled principally by the carbon content (C %) of the flux but is also affected by the type and particle size of the carbon. The required melting rate can be calculated by equation 8

$$MR = 2(w+t) Q_s V_c \quad (8)$$

It was mentioned above that the horizontal heat transfer is controlled by the thickness and crystalline fraction of the solid slag film and the latter property is also a function of the solid thickness. The thicknesses of the solid (d_s) and liquid (d_l) layers of the slag film are affected by the solidification temperature (T_{sol}) of the flux so that an increase in T_{sol} will increase d_s and decrease d_l. The break temperature, T_{br}, which is the temperature where, on cooling, there is a sudden increase in viscosity (i.e. where solids are precipitated), is preferred to T_{sol} since it is considered to provide a closer simulation of in-mould conditions. Analysis of plant data for the properties of fluxes used for various casting conditions at a large number of steelworks throughout the world showed that plots of viscosity versus break temperature tended to fall on 3 curves depending upon the nature of the steel grade (Figure 2). These plots represent lubrication (reciprocal viscosity) as a function of horizontal heat transfer (i.e. slag film thickness (d_s)).

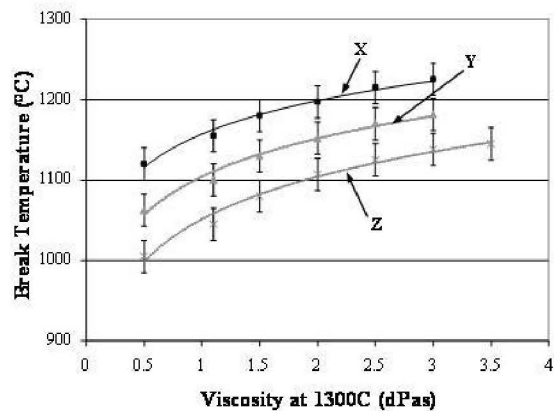


Fig. 2. Break temperature (T_{br}^{req}) as a function of viscosity (η^{req}) curve X for MC, crack- sensitive grades; Curve Z for HC sticker- sensitive grades and curve Y for all other (“intermediate”) grades; x= thin-slab data obtained earlier.

Medium carbon (MC) steels (C=0.07-0.15% C) are particularly prone to longitudinal cracking which occurs as a result of excessive heat extraction from the shell and thus a thick slag film (or high T_{br}) is required for casting these steel grades. High carbon (HC) steels are prone to sticker breakouts and it is necessary to produce a thick shell to minimize problems from stickers and this requires a thin glassy slag film (i.e. one with a low T_{br}). Thus the properties of fluxes for casting MC and HC steels tend to fall on curves X and Z, respectively in Figure 2⁷⁾. The properties of fluxes for casting all other grades fell on curve Y⁷⁾.

MC grades (C=0.07-0.15%)—curve X

$$T_{br}^{req} (^{\circ}\text{C}) = 1157 + 60 \ln \eta^{req} \quad (9)$$

HC grades (C>0.4%)—curve Z

$$T_{br}^{req} (^{\circ}\text{C}) = 1051 + 76.4 \ln \eta^{req} \quad (10)$$

Other grades -curve Y

$$T_{br}^{req} (^{\circ}\text{C}) = 1103 + 68.5 \ln \eta^{req} \quad (11)$$

In view of the planned expansion of production, it would seem appropriate to analyse and review the performance of the mould fluxes in current use for slab-casting at Khouzestan and Mobarakeh Steel Companies. This paper describes the first phase of a collaborative research programme between IUST and the two steel companies. In this we review the powder consumption, viscosities and break temperatures of the fluxes in current use and compare them with values recommended in the literature. In phase 2 of the programme, we hope to carry out work on slag films taken from the mould and measure slag pool depths etc. to maximise the performance of the mould fluxes used.

Experimental

The chemical compositions of the fluxes in current use are shown in Table 1. The fraction of the flux forming slag (f^*) was calculated using Equn 12. The normalised composition of the slag (i.e. without the carbon and carbonate) is also shown in parenthesis in Table 1.

$$f^* = \{100 - \%C_{free} - (44/12)(\%C_{tot} - \%C_{free})\} \quad (12)$$

The casting conditions are summarised in Table 2. Viscosity values of the flux were taken from the datasheets issued by the flux manufacturers. These may be calculated values and if so, would have an uncertainty of ca. $\pm 25\%$. No data for the break temperatures were cited in the datasheets, so values were calculated using equation 13; the values obtained are subject to an uncertainty of ca. $\pm 20^{\circ}\text{C}$.

$$T_{br} (^{\circ}\text{C}) = 1120 - 8.43\%Al_2O_3 - 3.3\%SiO_2 + 8.65\%CaO - 13.86\%MgO - 18.4\%Fe_2O_3 - 3.2\%MnO - 2.2\%K_2O - 6.47\%F \quad (13)$$

The only powder consumption (Q_t^{meas}) data available were global values (including wasted and discarded fluxes) for casting all steel grades with various fluxes. Consequently, these values will be higher than the operational values. Global values of Q_t^{meas} of (0.9-1.0) and (0.75 -0.85) kg tonne⁻¹ have been reported by Steel works I and II, respectively. Even the minimum global values lead to high powder consumption values. The minimum global values were used to obtain the Q_s^{meas} values (with the aid of equation 3) and the resulting values are given in Table 3.

Table 1. Chemical compositions of the fluxes in current use, the %Na₂O = %Na₂O + %K₂O: .()=normalised composition

Flux	%SiO ₂	%CaO	%Al ₂ O ₃	%MgO	%Na ₂ O	%F	%Fe ₂ O ₃	%C _{free}	%C _{tot}	f*
A	33.5 (38.1)	28 (31.9)	6.5 (7.4)	2 (2.3)	10.3 (11.7)	5.8 (6.6)	1.8 (2.2)	7.8	9.3	0.87
B	37.5 (39.9)	34.5 (36.8)	3 (3.2)	5 (5.3)	7 (7.5)	6 (6.4)	1 (1.1)	2.5	3.5	0.94
C	33.5 (40.9)	31 (37.9)	4.8 (5.9)	1 (1.2)	5.5 (6.7)	4.5 (5.5)	1.5 (1.8)	8.3	11.3	0.81
D	32.5 (35.7)	29.5 (32.5)	5 (5.5)	10.5 (11.6)	3 (3.3)	9 (9.9)	1.5 (1.6)	3.5	5.5	0.89

Table 2. Summary of casting conditions
{ }= Carbon Potential (CP) and ()= actual values

Works	Steel {CP}	Flux	w (m)	t (m)	V _c (m min ⁻¹)	R (m ⁻¹)	Q _s ^{req} Eq 4	Q _s ^{req} Eq 5	η ^{req} (dPas)	T _{br} ^{req} (°C)
I	LC	A	1.25	0.20	0.7-1.1	11.6	0.30	0.31	2.2 (3.1)	1150 (1058)
I	MC	B	1.25	0.20	0.7-1.1	11.6	0.30	0.31	2.2 (1.5)	1100 (1144)
II	Other Grade {0.16}	C	1.05-1.88	0.20	0.7-1.35	11-12	0.33-0.28	0.32	1.9 (4.8)	1147 (1156)
II	MC {0.12}	D	0.7-1.88	0.20	0.7-1.5	11.1-12.9	0.33-0.25	0.32	1.9 (1.1)	1195 (972)

Table 3. Comparison between the required and measured values of powder consumption, viscosity and break temperature

Steel (Works)	Flux	Q_s ($kg\ m^{-2}$)		Viscosity (dPas)		Break Temp ($^{\circ}C$)	
		Q_s^{req}	Q_s^{meas}	η^{req}	η^{meas}	T_{br}^{req}	T_{br}^{meas}
MC(I)	B	0.31	0.55	2.2	1.5	1100	1144
(II)	D	0.32	0.44	1.9	1.1	1195	972
LC (I)	A	0.30	0.51	2.2	3.1	1150	1058
C=0.16- 0.21%(II)	C	0.32	0.41	1.9	4.8	1195	1156

The calculations were performed in the following manner:

- (i) The values of R were calculated from the mould dimensions (w,t) : $R=2(w+t)/wt$.
- (ii) Q_s^{req} was calculated ($= 2/R \cdot 5$) for the values of R
- (iii) Q_s^{req} was also calculated from equations 3 and 5 using a mean value of R.
- (iv) The required flux viscosity at $1300^{\circ}C$ (η^{req}) was calculated from equation 7 for the highest, lowest and mean casting speeds and the mean Q_s^{req} value.
- (v) The carbon potential (CP) of the steels was then calculated to determine which equation (9,10 or 11) or curve to use (X, Y or Z)

$$CP = \%C + 0.02\%Mn - 0.1(\%Si + \%Mo) \quad (14)$$

- (vi) The value of (η^{req}) derived for the mean casting speed was then used to calculate the required break temperature (T_{br}^{req}).

The results obtained for the various parameters are given in Table 2.

Results and Discussion

The calculated values for Q_s^{req} , η^{req} and T_{br}^{req} are compared with actual values of the flux in Table 3. These values are also presented in Figures 3 and 4 where the measured values are compared with the required values represented by the appropriate curve for the steel.

Inspection of the results given in Table 3 and Figures 3 and 4 indicate the following:

- (i) The free carbon contents of fluxes A and C are much higher than those usually used for casting slabs; this could lead to (a) shallow slag pool depths and (ii) low powder consumption.
- (ii) The available powder consumption data are not reliable enough to carry out further analysis of the fluxes. More accurate values for the operational powder consumption will be obtained in the second phase of this project which should allow a reliable analysis of the level of lubrication being supplied by the flux.
- (iii) The actual viscosity and break temperatures are not in good agreement with the required values. Fox^{5,7} reported that 85-90% of the fluxes examined conformed with the relations shown in Figure 2 but 10-15% of the fluxes did not fit the empirical rules but appeared to work well in practice. This may be the case here, but this study underlines the need to

scrutinize the performances of the fluxes. High viscosities (e.g. flux C) would lead to low powder consumption and low break temperatures (e.g. flux C) would lead to excessive heat flux (e.g. flux D) which is particularly critical when casting MC grades prone to longitudinal cracking.

(iv) The values for the break temperature and probably the viscosity are calculated values, and it is recommended that actual measurements should be carried out to help the decision making.

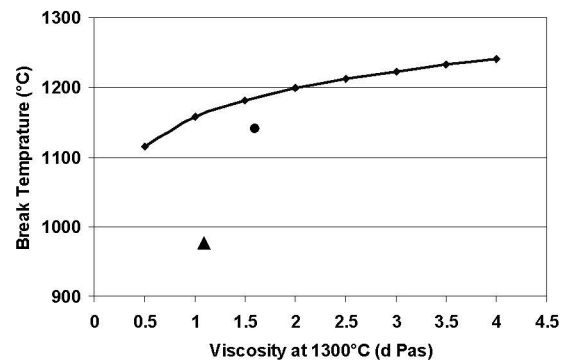


Fig. 3. Break temperature (T_{br}^{req}) as a function of viscosity (η^{req}) curve for casting MC steels; symbols are experimental values (●: MC(I), ▲: MC(II)) and curve gives required values.

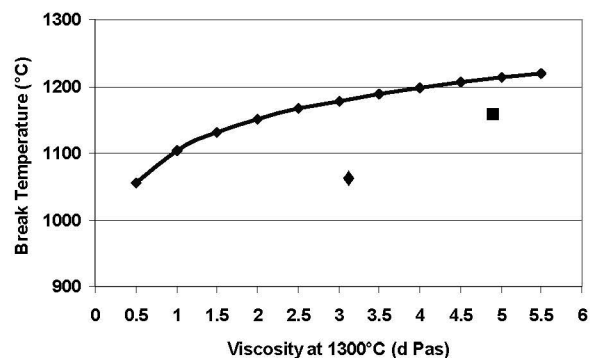


Fig. 4. Break temperature (T_{br}^{req}) as a function of viscosity (η^{req}) curve for casting other ("intermediate") steels; symbols are experimental values (◆: LC(I), ■: C>0.16%(II)) and curve gives required values.

In Steel companies, I experienced problems with (a) metal overflows ("bleeds") and (ii) depressions on

the surface of the slabs as shown in Figure 5. Depressions are usually caused by

1. Poor mould level control⁸⁻¹⁰.
2. Poor molten slag infiltration (i.e. powder consumption).

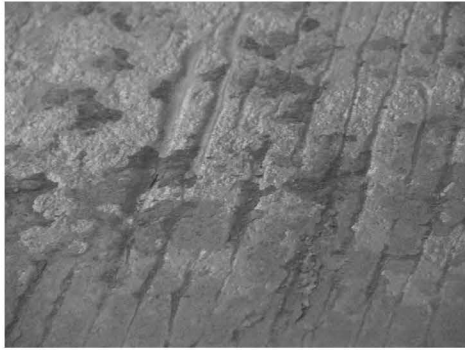


Fig. 5. Photograph of a slab surface showing “metal overflows” and “depressions”.

Metal overflows are caused by¹¹:

1. the steel coming in contact with carbon (from the slag rim or the powder bed) thereby creating a low-melting metal which can overflow the solidified metal
2. cut-off of the molten slag infiltration (by the slag rim)
3. a shallow slag pool.

Thus, poor mould level control and the shutting – off of slag infiltration would promote both types of defects. In this case, the high carbon content (7.8% in flux A) would cause (i) a low melting rate which would lead to a shallow slag pool (ii) a source of carbon for the contamination of the metal (via the slag rim or the powder bed). Thus the incidence of both defects could be improved by (i) improving mould level control and (ii) reducing the Carbon content of the flux so that it forms a slag pool of >10mm.

Conclusions

1- Calculations have shown that the actual flux properties (Q_s^{meas} , η^{meas} , $T_{\text{br}}^{\text{meas}}$) do not agree with the required values calculated from published empirical rules; this does not necessarily mean that the fluxes

are not working well, but it does mean that a complete review of their performance is essential and should be carried out before the planned increase in production.

2- Accurate data are needed for the powder consumption to check the level of lubrication being supplied by the flux.

3- The metal overflows and depressions on the surface of the slab are probably related to the combined effects of poor mould level control and the high carbon content of the flux, which could result in (a) low melting rates and consequently, shallow slag pool depth and (b) a low –melting metal due to carbon pick-up.

4. Measured values of the viscosity and break temperatures are needed to help the decision making process.

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