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DISCRIMINATION BETWEEN LONG SLAG AND SHORT SLAG

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ABSTRACT Based on observed η vs T relationships for silicate melts and CaF_2 – based slag melts, the R_{min} is raised to discriminate between long slag and short slag by quoting the mathematical concept of curvature radius . The R_{min} values of the smallest curvature radius of η vs T plot implicate the apparent activation energy E_η , hemispherical softening point temperature T_0 and viscosity η_R at the character temperature T_R . Using CaF_2 and SiO_2 as reference standard of short slag and long slag respectively, the classification of slags has been made. Calculation of R_{min} for flux or slag is of significance in ESR , protective casting and welding.

KEY WORDS slag, viscosity, ESR, welding

IN iron and steel making practices, data on melting and softening points of slag are insufficient to describe the solidifying character of molten slag and to evaluate its behaviour as liquid from the metallurgical standpoint. An essential slag characterisic is its fluidity or solidifying behaviour, which is governed by the relatonship of viscosity and temperature . The viscosity variation curves are patterned differently for various slags. The so – called short slag means its viscosity change occurs in a narrow interval of temperatures than the long slag does . And the concept of long or short slag is usually limited during the metallurgical practice because of having no proper numerical evaluation as slag basic capability.

The method to account for the solidifying characteristic of molten slag was given by reference [1]. The temperature dependence of viscosity of molten slag was expressed by an Arrhenius – type equation as

$$\eta = \eta_0 \exp(E_\eta / KBT) \tag{1}$$

where the apparent activiation energy E_η increases with the sharp decrease of temperature. If the $\ln\eta$ is not linear with $1/T$ experimentally for some slag melts, the $\ln\eta$ vs $1/T$ plots are considered as two linked straight – line segments . The angle of α between two segments can be used to discriminate the solidifying characteristic of molten slags. The smaller the broken line angle , the shorter the slag . However, this method is inadequate in the fact that the broken angle cannot uniquely be determined by choosing cross point of straight-line segments. In many cases, the curvature of $\ln\eta$ vs $1/T$ is likely to close to a straight-line with a narrow span of temperature. It is very difficult to compare the changes of α of long slag and short one.

In this work, the R_{min} is raised to discriminate long slag and short slag by quoting the mathematical concept of curvature radius, which can be uniquely determined by measuring the softening point of slag and the change of viscosity with temperature for molten slags.

1 MATHEMATICAL TREATMENT

For all metallurgical slags, dependences of viscosity on temperature have the same trend as shown in Fig.1.

At very high temperature, slag may be liquidus with very low viscosity and the curve of viscosity changing with temperature shows plateau . When the temperature drops to the softening interval, the viscosity increases greatly and the curve shows steep. So there must be a point where exists the smallest curvature radius R_{min}, and the R_{min} value can present essentially the solidifying charactristic of molten slag.

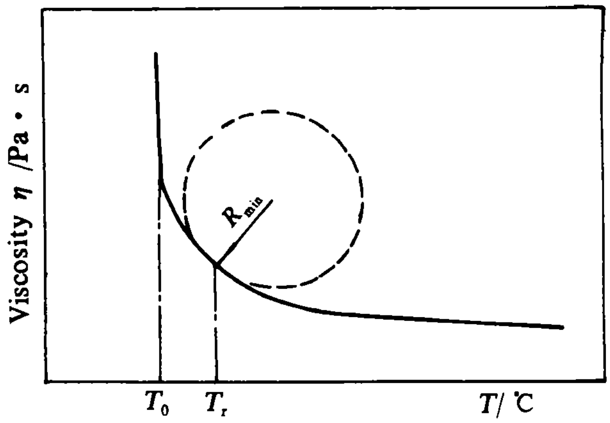

Fig. 1 The dependence of η on T

The departure from equation (1) can be represented by

$$\ln\eta = a + b/(T - T_0) \qquad (2)$$

where a and b are constants and T_0 is hemispherical softening point temperature measured experimentally. Equation (2) is known to cover a wide variety of slag melts over a larger span of temperature and hence a larger span of viscosity [2]. To take derivation of η with respect to T, thus:

$$d\eta/dT = -2.303b\eta(T - T_0)^2 \qquad (3)$$

and

$$d^2\eta/dT^2 = 2.303b\eta[2 + 2.303b/(T - T_0)]/(T - T_0)^3 \qquad (4)$$

The curvature is given by the expression

$$k = y''/(1 + y'^2)^{3/2} \qquad (5)$$

where $y' = d\eta/dT$, and $y'' = d^2\eta/dT^2$.

Put $R = 1/k$, the R value is generally called the curvature radus. Introducing equations (3) to (5), follows the expression for the cruvature radius of η vs T plots.

$$R=\frac{(T-T_0)^3[1+5.302b^2\eta^2/(T-T_0)^4]^{3/2}}{2.303\eta[2+2.303b/(T-T_0)]} \tag{6}$$

From equation (6), the smallest curvature radius R_{min} can be calculated by using the relationship of η and T of molten slags. Using the R_{min} of CaF_2 and SiO_2 as reference standards of short and long slags respectively, the solidifying characteristic or softening interval for some typical slags or fluxes can be compared numerically.

2 EXPERIMENTAL

The apparatus used for measurement of hemispherical softening point temperature is a GX−1 type high−temperature physical propterty meter. The shape change of test slag block of with tempterature is visualized by means of continuous photography, and the determination of hemispherical softening point temperature T_0 is shown in Fig. 2.

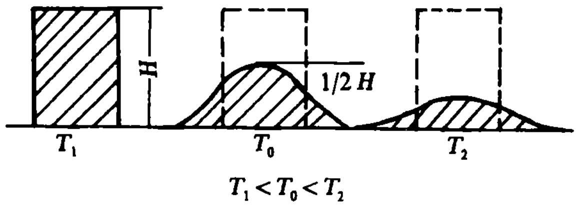

Fig. 2 Hemispherical softening point temperature *T*

To measure accurarily, the heating rate of sample must be strickly controlled.

Rotation method [3] used for measuring the viscosity of molten slag is carried out in CM−1 type viscosity meter, which is equipped with micro−computer to control temperaure and deals with data. The carbon resistance heating furnace is used, with the temperature control accuracy of ±1.5 ℃ (1600 ℃) and constant temperature band not less than 5 cm (±3 ℃). To avoide the reactions between the measuring parts and molten slags, the materials of the immersed body (usually a cylinder) and crucible liner are molybdenum (or any other appropriate material).

In testing the immersed body rotates in the melts while the crucible remains stationary. The coefficient of viscosity is calculated by

$$\eta=K\cdot G/n \tag{7}$$

Where η − coefficient of viscosity; G − twist angle of torsion fibre; n − revolution speed of immersed body; and k − apparatus constant which is derived from calibration curves using liquids of known viscosity.

3 RESULTS AND DISCUSSION

The three types of slag or flux were choosed for measurement of hemisphere point temperature and viscosity. Their chemical composition is shown in table 1.

Table 1 Composition of slags or fluxes (%)

Slag type	No	SiO_2	Al_2O_3	CaO	MgO	CaF_2	MnO	TiO_2	FeO
Electroslag	1	13.10	9.59	17.44	13.62	47.08	0.02	0.04	0.01
remelting	2	15.50	8.96	15.56	12.37	48.98	0.28	0.20	
	3	12.90	5.27	19.94	11.70	46.55	0.05	0.06	
	4	1.98	7.63	26.99	15.32	46.69	0.02	0.04	
Continuous	5	39.92	14.73	16.40	8.66	4.43		0.45	0.73
casting	6	41.10	10.81	15.41	2.92	16.06		0.70	
	7	40.88	14.96	18.14	10.23	4.45		0.45	
	8	41.89	20.93	12.42	3.06	4.57		0.60	
Submerged	9*	7.82	27.57	4.42		46.63	1.99		0.26
-arc welding	10*	17.86	21.04	9.20	14.25	24.69	5.39		0.54

* The Na_2O+K_2O contents in samples 9 and 10 are 2.2 % and 2.0%, respectively.

For all slags studied in this work, the $\ln\eta$ is very linear with $1/(T-T_0)$ from T_0 to 1550 ℃, which is shown in Fig. 3. The hemisphere point temperature T_0 is a likely modified coefficient of Arrhenius-type (see equation (1)) of viscosity of molten slag. Solidifying character parameters of slags or fluxes in table 1 are shown in table 2 . The η_R was calculated by use of equation (2) with substituting characteristic temperature T_R at which the viscosity begins to increase sharply. The data of CaF_2 and SiO_2 are extrapolated from the results of Mills and Bacdris [4, 5] and present the extreme condition of solidifying behaviour for all metallurgical slags.

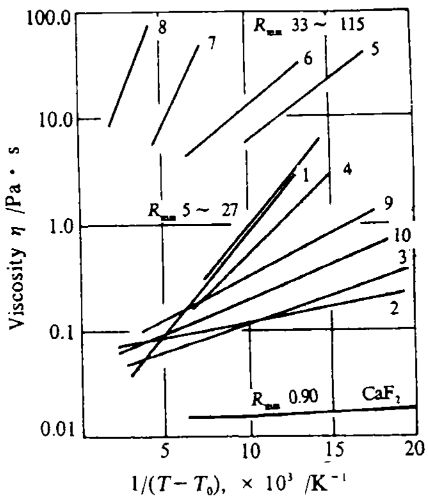

Fig. 3 Temperature dependence of viscosity of slag or flux

Sample No.1 to No. 4 slags are usually applied to ESR process, the R_{min} values of them are from 10 to 20. These slag systems are favourable for good surface of ESR ingot. According to results in reference [6], long slags remain fluid or mushy in a wide temperature range and are likely to give thin slag skins on the ingot surface. On the contrary, short slags rapidly become viscous on cooling and likely to give thick slag skins which cause poor ingot surface. Therefore, the R_{min} value can be used as a reference point for judging physical property of selective slag systems [7] .

For continous casting process, the R_{min} value of slags used is large by comparison with ESR slag, seeing samples No. 5 to No. 10 listed in table 2. A larger span of solidifying temperature implicates the formation of glassy slag films on the surface of casting slab or billet and favous the improvement of surface quality of product .

Applications of the R_{min} to welding process still exist problems, because the requirement of physical and chemical properties for flux is dependent on welding method

Table 2 Temperament dependence of viscosity of slag or flux

No	Experimental formula		R_{min}	$T_R - T_0$ / ℃	η_R /Pa·s
1	$\lg\eta = -2.021 + 191.86/(T - 1\,149)$	($n=10$, $r=0.91$)	19.85	66	7.69
2	$\lg\eta = -1.187 + 30.26/(T - 1\,115)$	($n=10$, $r=0.96$)	7.68	17	3.92
3	$\lg\eta = -1.456 + 53.74/(T - 1\,120)$	($n=5$, $r=0.98$)	10.01	26	4.08
4	$\lg\eta = -1.776 + 151.3/(T - 1\,223)$	($n=11$, $r=0.90$)	18.94	57	7.56
5	$\lg\eta = -0.393 + 117.27/(T - 1\,206)$	($n=3$, $r=0.998$)	33.83	72	17.21
6	$\lg\eta = -0.115 + 120.85/(T - 1\,115)$	($n=5$, $r=0.986$)	41.72	83	21.93
7	$\lg\eta = -0.727 + 323.9/(T - 1\,167)$	($n=4$, $r=0.995$)	57.97	151	26.18
8	$\lg\eta = 0.108 + 409.5/(T - 1\,210)$	($n=3$, $r=0.968$)	114.78	249	56.57
9	$\lg\eta = -1.293 + 83.7/(T - 1\,306)$	($n=6$, $r=0.867$)	15.22	39	7.13
10	$\lg\eta = -1.338 + 66.3/(T - 1\,100)$	($n=14$, $r=0.967$)	12.43	32	5.42
CaF_2	$\lg\eta = -1.82 + 7.096/(T - 1\,360)$		1.79	4	0.899
SiO_2	$\lg\eta = 1.95 + 1\,369/(T - 1\,470)$		~ 1 045	~ 1 500	~ 728.9

or welding process. The flux must be fluid enough to flow and thus cover the molten welding pool, but it also be viscous enough so that it does not run off the molten metal and prevent the weld pool oxidization. Generally, the flux with short slag property is adapted for vertical−fall welding operation. Therefore, the properties mentioned above for weld flux are more important than the solidifying behaviour of flux melts.

Many empircal correlations have been made between viscosity and composition [8] in this work, an attempt has been made to determine the R_{min} value resposible for composition of slag. For the $CaF_2-Al_2O_3-CaO-SiO_2-MgO$ system this can be written as

$$R_{min} = 66.34 - 1.09B - 1.16C_{CaF_2} \tag{8}$$

where C_{CaF_2} is the percent of CaF_2, and B the basic capability expressed as

$$B = [(C_{CaO} + C_{MgO})/(C_{Al_2O_3} + C_{SiO_2})]$$

where C_{CaO}, C_{MgO}, $C_{Al_2O_3}$ and C_{SiO_2} are the percents of CaO, MgO, Al_2O_3 and SiO_2, respectively. This calculation of R_{min} is applicable to the range of B from 0.7 to 4 and CaF_2 content from 5% to 45%.

4 CONCLUSIONS

The long or short slag can be discrimined by R_{min} which is the smallest curvation radius of η vs T plot at character temperature T_R. Using the R_{min} value of CaF_2 and SiO_2 as reference standard of short slag and long slag respectively, the solidifying character for some typical slags and fluxes used for ESR process, continuous casting process and welding operation can be compared numerically. This new concept expressing the temperature depenence of viscosity of slag has been applied to select slag system of large scale ESR process.

(To be continued on page 34)

航空齿轮疲劳强度的可靠性

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摘要　采用成组试验法，对40副航空用16NCD13钢渗碳淬火齿轮进行齿面疲劳强度试验研究，分别在4个应力水平上取得了齿面出现点蚀时和点蚀达到失效判据时的疲劳寿命样本．经统计分析，判明了疲劳寿命的分布规律并对分布参数进行了估计．在此基础上拟合出了置信度为95%、可靠度为99.99%的齿面接触疲劳极限应力值，为这种齿轮的可靠性设计和寿命预测提供了基础数据．
关键词　航空齿轮，齿面接触疲劳强度，R－S－N 曲线
中图分类号　TH132.41

(*Continued from page 23*)

REFERENCES

1 Семи и п. и д р Металлургия Чхгуна. М : еталлургия. 1968
2 Napolitano A, Howkins E G. J Res Nat Bur Stand, 1964, 68A, 439
3 Couche M. Ann Chem Phys, 1890, 6: 433
4 Mills K C. NPL Report, 1977, 65
5 Bockris J O'M. Trans Faraday Soc, 1955, 51 : 1734
6 Medovar B I. Proceeding of 7th ICVM, Tokyo, Japan, 1982
7 Chu Shaojun. Engineering Chemistry and Metallurgy (in chinese), 1992, 13 (2) : 111
8 Эятькова Л Р. Металлы, 1981(3): 42

长渣和短渣的数值判据

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摘要　在研究硅酸盐熔体和氟化钙基熔渣粘度随温度变化规律的基础上，引入最小曲率半径 R_{min} 的概念作为"长渣"和"短渣"的数值判据．R_{min} 值隐含了表征熔体粘度表观活化能 E_η，熔化半球点温度 T_0 和在特征温度 T_R 的熔体粘度值 η_R．以 CaF、SiO_2 作为典型"短渣"、"长渣"，对所研究的渣系进行分类．不同熔剂或熔渣的 R_{min} 计算值对电渣重熔、保护浇铸以及焊接的工艺过程有一定指导意义．
关键词　熔渣，粘度，电渣冶金，焊接
中图分类号　TF14, TG444