Indicator W_{so} : A New Parameter for Characterization of Protective Coating Efficiency Against Humidity

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This paper concerns the development of W_{so} , an indicator of the efficient protection against humidity, as a new parameter characterizing protective coatings. This indicator determines to what degree the covering of cores and sand molds influences, advantageously or disadvantageously, the humidity absorption from surroundings into surface layers, in comparison with layers without covering, which absorb the moisture at high-humidity conditions of atmospheric air. Simultaneously, this indicator will allow for an efficient comparison of tendencies of individual coatings for moisture sorption depending on the number of their layers. Thus, it can serve as a guideline in selecting the coating type for the molding sand on which it will be deposited, while taking into account the time of waiting—of molds and cores covered with coatings—on pouring with liquid metal and the atmospheric conditions to which they will be exposed.

Keywords moisture sorption, molding sand, protective coating, surface layer

1. Introduction

Protective coatings applied to cores and sand molds are, in foundry practice, widely distributed materials. In accordance with environmental protection, only the water-based coatings, which are environmentally friendly, should be used. Nevertheless, the alcohol-based coatings are common as well. The coatings are mainly used for protection against the liquid metal penetration into deeper layers of sand molds and for decreasing the tendency of molding sands to stick to the cast's surface (Ref 1–4). Despite that, the protection against humidity as a result of coating is not considered by either the literature or material manufacturers. However, since there is a chance of an occurrence of cast surface defects, it seems to be important, especially regarding defects of gaseous origin (Ref 5, 6). Even more so, because the authors proved in the previous studies (Ref 7–9) that in conditions of high relative humidity of air and temperature, the water from surroundings can be absorbed into surface layers of sand molds elements (including those covered by protective coatings). Therefore, it was decided to develop the indicator of the efficient protection W_{so} , which will allow estimating whether covering the cores and molds with coatings influences, advantageously or disadvantageously, the moisture sorption from surroundings.

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2. Materials and Methods

The determination of the indicator of the efficient protection against humidity W_{so} was performed on cuboidal shaped elements (Fig. 1) of dimensions $50 \times 30 \times 5$ mm, made of molding sands with organic (alkyd resin and furan resin) and inorganic (hydrated sodium silicate—water glass) binders (see Table 1).

The 5 mm thickness of the shaped element, at double-sided moisture exchanges (presented schematically in Fig. 2) which occurs during tests, reflects conditions in surface layers of molds and cores down to the depth of 2.5 mm. Alcohol-based and water-based zirconium coatings were applied as the protective coatings.

The investigation method was quantitative measurements of the moisture sorption based on the gravimetric method (described in detail in Ref 7), with simultaneous consideration of the modification allowing to deposit the protective coating (Ref 8). The immersion time was 5 s at the relative viscosity of coatings. It was measured by a Ford Cup with an outflow hole diameter equal to 4 mm. The prepared samples were placed on the measuring stand for 12 h under the thermal humid conditions as follows:

- 27–32 °C—air temperature,
- Above 95% of the relative humidity of the atmospheric air. Changes in the sample weight, due to the moisture absorbed from surroundings, were continuously measured and recorded every 30 s with a computer.

2.1 Determination of the Indicator

The determination of the indicator of the efficient protection against humidity— W_{so} —is done based on the collected data concerning increases in the sample weight due to the moisture sorption from the surroundings in time. The indicator W_{so} is expressed by Eq 1:

$$W_{so} = \frac{I_{w_0} - I_{w_p}}{I_{w_0}} \cdot 100\% \quad (\text{Eq 1})$$

Fig. 1 Shaped elements for testing: (a) without coating, (b) with one layer of zirconium coating, (c) with two layers of zirconium coating

Table 1 Molding sands used in tests

Molding sand	Component	Amount
With alkyd resin	Sand grains	100 p. p. w.
	Silica sand	
	Binder	1,3 p. p. w.
	Resin SL 2002	
	Hardener	25% to the binder
With furan resin	KL	
	Sand grains	100 p. p. w.
	silica sand	
	Binder	1,2 p. p. w.
	Resin Furanol FR75	
With hydrated sodium silicate	Hardener	60% to the binder
	PU6	
	Sand grains	100 p. p. w.
	Silica sand	
	Binder	3,5 p. p. w.
	Sodium water glass	
	Hardener	10% to the binder
	Flodur FM5

Fig. 2 Scheme of moisture exchange between surroundings and the shaped element

where W_{so} is an indicator of the efficient protection against humidity (%), I_{w_0} the humidity amount of the shaped element without the protective coating (g/cm^2) and I_{w_p} the humidity amount of the shaped element covered by the protective coating (g/cm^2).

The positive indicator value shows that the amount of the moisture absorbed by surface layers covered by coatings was smaller (in a percentage formulation) than by layers not covered. In other words, it shows that these coatings provide an efficient protection against humidity. In a similar fashion, the negative value indicates that layers covered with coatings absorb more moisture than layers not covered, which means that the protective function is not provided.

The W_{so} indicator can be determined for the arbitrary period during which cores or sand molds are exposed to the atmospheric conditions influence.

2.2 Analysis of the Results

Figure 3, 4 and 5 represents the course of the moisture sorption into surface layers of cores made from molding sands with different types of binders. The collected data are a basis to determine the W_{so} indicator. Figure 6, 7 and 8 shows the graphic interpretation. Another aspect, which must be mentioned, is the fact that the analysis of the sorption process, and in consequence of the W_{so} indicator, has been presented here only for the relatively high air humidity (over 95%) and temperature (27–32 °C). Moreover, it should be mentioned that these analyses can be done for any ambient conditions.

The course of the moisture sorption varies in terms of the sorption intensity depending on the kind of molding sand, particularly on the type of the binder. Molding sands with organic binder (alkyd resin—Fig. 3) are characterized by lower moisture sorption ability, which is equal to approximately $0.0075 \text{ g}/\text{cm}^2$ in the case of samples without protective coatings after 12-h exposure to atmospheric condition. This means that during that time (12 h), 0.0075 g of water from surroundings is penetrating each unit of the core's surface.

According to the diagram, the second molding sand with organic binder (furan resin—Fig. 4) shows a tendency to much higher weight increase as a result of absorbed moisture. In comparison with the alkyd molding sand, a 70% increase is noted. Notwithstanding, the most susceptible to humid air is molding sand with inorganic binder (water glass—Fig. 5). The diagram depicts that during the 12-h exposure to the ambient condition influence, $0.024 \text{ g}/\text{cm}^2$ moisture was absorbed into the surface layers of that molding sand.

Fig. 3 Process course of the moisture sorption (an increase in the moisture weight Δm and kinetics $\Delta m/\Delta t$) into surface layers of the sand mold made of molding sand with alkyd resin

Fig. 4 Process course of the moisture sorption (an increase in the moisture weight Δm and kinetics $\Delta m/\Delta t$) into surface layers of the sand mold made of molding sand with furan resin

However, application of zirconium water-based and alcohol-based coatings can significantly change the character of the moisture sorption into surface layers of sand cores in the case of each analyzed molding sand. The effectiveness of the protective function changes over time. To observe these changes and for the comparison of efficiency of selected coatings and number of their layers in moisture sorption, the W_{so} indicator was developed.

According to Fig. 6, 1-h exposure to the atmospheric conditions negatively affects the cores made of molding sands with resins, especially in the case of using the water-based coating. For the alkyd molding sand with a single layer of water-based coating, the W_{so} indicator is equal $W_{so1} = -85\%$, whereas for double layer it is $W_{so1} = -125\%$. Similarly, the protective action of this coating, applied on furan cores, is

ineffective. Only in combination with molding sand with water glass, the water-based coating generally does not affect molding sand sorption ability, which is indeed high. The alcohol-based coating shows greater efficiency in protection. Furthermore, a single layer of this coating's type protects sand cores with inorganic binder significantly well. In the case of furan molding sand, alcohol-based coating's efficient protection against humidity oscillates around 20%. The same coating negatively affects surface layers of molding sands with alkyd resin.

Increasing the exposure time up to 6 h (Fig. 7) decreases the effectiveness of protection against the humid air of the alcohol-based coatings applied on cores made of molding sand with furan resin and water glass. Simultaneously, the water-based coatings have a negative impact on moisture sorption in

Fig. 5 Process course of the moisture sorption (an increase in the moisture weight Δm and kinetics $\Delta m/\Delta t$) into surface layers of the sand mold made of molding sand with hydrated sodium silicate (water glass)

Fig. 6 Indicator of effective protection against humidity for surface layers with protective coatings exposed for 1-h atmospheric conditions influence

molding sands with resins and have no influence on molding sands with inorganic binder.

Figure 8 shows that a single layer of alcohol-based coating applied on cores, independently of the molding sand's type they are made from, is the best choice in terms of protection. Nevertheless, the efficient protection of this coating is not too high. Its maximum value of the W_{so} indicator was round 20%, which is characteristic for application on cores made from molding sands with furan resin.

On the other hand, the water-based zirconium coatings increase the molding sand's tendency to moisture sorption processes. The efficient protective indicator W_{so} holds negative values for both molding sands with resins during the entire analyzed period (12 h). For the molding sands with water glass,

the W_{so} indicator shows a negative value for double layers and oscillates around 0 for a single one.

It should be considered that the alcohol-based coatings protect the surface layers of elements of sand molds against humidity much better if they are applied in a single layer. In other words, if in the foundry's work schedule, the time between the application of the protective coatings on cores and molds, made with a different type of molding sands with chemical binders (alkyd resin, furan resin and water glass), and pouring out the mold with the liquid metal is 12 h, in terms of moisture sorption under the humid air conditions, the deposition of double-layer coating (regardless of the coating type) seems to be pointless. Moreover, if the intended aims of applying coatings, such as protection against the liquid metal

Fig. 7 Indicator of effective protection against humidity for surface layers with protective coatings exposed for 6-h atmospheric conditions influence

Fig. 8 Indicator of effective protection against humidity for surface layers with protective coatings exposed for 12-h atmospheric conditions influence

penetration into the deeper layers of sand mold or decreasing tendency to stick the molding sand to the surface of cast, are accomplished by using a single layer of protective coating, then the application of larger numbers of layers would be uneconomic as well as risky because of the greater possibility of defects occurring in the casts, especially of a gaseous origin.

3. Conclusions

The W_{so} indicator presents effectiveness of applying protective coatings for cores and molds against humid air. It can be determined for the arbitrary period during which elements of

cast molds are exposed to the atmospheric condition as well as various ambient conditions, for example, the conditions which are characteristic during the season. The indicator can be easily adjusted to the work schedule of foundries. Thus, it can have practical implication as a pointer or a guideline in the selection of protective coatings (the type of coating and the number of layers) depending on molding sand the elements of sand mold were made of, atmospheric conditions the elements are exposed to and the length of the exposure. In this way, the process of excessive moisture sorption from surroundings through the surface layers of sand molds can be minimized, which means that the amount of accumulated water in the very surface layers is decreased, while consequently decreasing the possibility of defects occurring in the casts, especially of a gaseous origin.

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