SAND-SODIUM-SILICATE MIXTURES STRUCTURED IN STEAM-MICROWAVE ENVIRONMENT EFFECTIVE VALUES OF THERMO-PHYSICAL PROPERTIES

Purpose. Sand-sodium-silicate mixtures, structured by steam-microwave solidification, thermo-physical properties integral-effective values were determined on Al-Mg alloy and graphite cast iron pouring determination. Sand-sodium-silicate mixture apparent density changing according to quartz sand, cladded with sodium silicate solute, fractional composition and its influence on BrA9Zh3L bronze microstructure establishment.

Methodology. Quartz sand with 0.23 mm average particle size, sodium silicate solute, aluminum alloy with 8.5 % Mg, flake graphite cast iron SCh200 (DSTU 8833:2019), bronze BrA9Zh3L (GOST 493-79) were used. Mixtures structuring was carried out in 700 W magnetron power microwave furnace. Sand-sodium-silicate mixture thermo-physics integral-effective values during Al-Mg alloy and graphite cast iron pouring determination. Sand-sodium-silicate mixture apparent density was determined on samples 50 x 120 mm dimension. Metallographic studies were realized using Neophot-21 optical microscope.

Findings. It was found that with sodium silicate solute, used for sand cladding, amount increasing from 0.5 to 3 % mold material apparent density decreases and thermal activity lowers. This leads to castings grains size increasing. Mixture sodium silicate solute content was recommended limiting 1.5 % for fine-grained microstructure castings obtaining and cladded sand using, which particles pass through mesh side less 0.315 mm sieve. Sands with sodium silicate solute content more than 1.5 %, which don’t pass through sieve 0.4 mm mesh side, were recommended as casting molds heat-insulating material using.

Originality. For the first time, when aluminum-magnesium alloy and graphite cast iron pouring, quartz sand cladded with sodium silicate solute in amount from 0.5 to 3.0 % (weight, over 100 % quartz sand), steam-microwave radiation structured, thermo-physical properties integral-effective values were determined.

Practical value. Data obtained using will improve castings solidification time and rate analytical calculations accuracy, forecast level and residual stresses sign in them, shrinkage defects locations. This will reduce casting technology developing time and costs and castings manufacturability.

Keywords: sand-sodium-silicate mixture, steam-microwave solidification, thermo-physical properties, mold, casting, microstructure.
Influence of iron casting thickness (δ) on molding mixture
thermo-physical properties

| δ, mm | ρm, kg/m³ | c₂, J/kg·deg | λ₂, W/m·deg | d₂, 10⁶, m³/s | b₂, W·s⁰.⁸/m⁰.⁸ |
|-------|-----------|---------------|-------------|---------------|-----------------|
| 10    | 1700      | 992           | 1.100       | 0.40          | 1372            |
| 20    | 1760      | 963           | 1.380       | 0.50          | 1540            |
| 30    | 1720      | 1030          | 1.550       | 0.53          | 1660            |
| 50    | 1670      | 1063          | 1.640       | 0.56          | 1708            |

Molding mixture thermo-physical properties for aluminum, cast iron and steel castings

| Metal, alloy | TCR, °C | ρm, kg/m³ | c₂, J/kg·deg | λ₂, W/m·deg | b₂, W·s⁰.⁸/m⁰.⁸ |
|-------------|---------|-----------|---------------|-------------|-----------------|
| Al          | 660     | 1400      | 1070          | 0.400       | 775             |
|           |         | 1600      | 1030          | 0.451       | 860             |
|           |         | 1750      | 1000          | 0.518       | 945             |
| Cast Iron   | 1147    | 1400      | 1300          | 0.732       | 1157            |
|           |         | 1600      | 1280          | 0.715       | 1210            |
|           |         | 1750      | 1237          | 0.707       | 1300            |
| Steel (C = 0.3 %) | 1487 | 1400 | 1425 | 0.898 | 1340 |
|           |         | 1600      | 1425          | 0.840       | 1383            |
|           |         | 1750      | 1380          | 0.828       | 1420            |

\[ b_2 = 2 \frac{V_{\text{CAST}}}{F_{\text{CAS}}} \rho_1 r \left( \frac{t_{\text{CRT}} - t_M}{\sqrt{\tau_{\text{SOL}}}} \right), \tag{1} \]

\[ q_{\text{SOLH}} = q_{\text{OHEAT}} + r + \frac{2}{3} c_1 (\theta_{\text{SOLET}} - \theta_{\text{ET}}); \]

\[ \theta_{\text{SOLET}} = t_{\text{CRT}} - t_M; \quad \theta_{\text{ET}} = t_{\text{OHEAT}} - t_M. \]

From formulas (1, 2) analysis it follows that casting solidification time is inversely proportional to \( b_2 \) square and (Tables 1 and 2) can vary within fairly wide range due, in particular, to structured mixture apparent density changes. That is, by structured mixture only apparent density changing, it is possible to significantly change the values of \( \lambda_2, b_2 \) and, accordingly, casting solidification time and rate.

Materials and methods. Quartz sand with an average particle size of 0.23 mm; sodium silicate solute (SSS) with silicate modulus of 2.88–2.93 and specific gravity of 1.42–1.44 g/cm³; aluminum alloy with 8.5 % Mg; gray cast iron with flake graphite SCh200 (DSTU 8833:2019); bronze BrA9Zh3L (GOST 493-79) have been used in this study.

For integral-effective values of SSSM thermo-physical properties determination, casting mold has been made according to SSS-process. Structured mixtures were quartz sand cladded with 0.5, 1.5 and 3.0 % SSS (by weight, over 100 % sand).

For structuring, quartz sand has been cladded with sodium silicate solute and poured into polypropylene box. Before sand filling, water charge has been installed at the box bottom - foam urethane sponge saturated with 1–2 g water. At the end of filling sand has been compacted for 10–60 s by vibration with vibration frequency of 50 Hz and amplitude of 0.8–1.0 mm. Cladded sand structuring has been carried out in microwave furnace with magnetron power of 700 W for 12–17 minutes.

Chromel-alumel thermocouples have been used for aluminum-magnesium alloy castings temperature, as well as mold temperature, measuring. Tungsten-molybdenum thermocouple has been used for temperature of gray cast iron casting measuring.

Work piece of this thermocouple has been covered with refractory paint layer up to 0.2 mm thick.

All thermocouples have been placed in one horizontal plane of casting mold in accordance with scheme presented in Fig. 1.

Change in thermocouples working junction temperature has been recorded with an electronic potentiometer at recording frequency of 2 s.

Alloys accepted for research have been poured into molds with working cavity dimensions \( \varnothing 30 \times 330 \) mm. Obtained data processing and thermo-physical properties integral-effective values calculation of tested mixtures have been carried out according to G. A. Anisovich (1979) method.

Structured mixtures apparent density has been determined on samples \( \varnothing 50 \times 120 \) mm and calculated by formula

\[ \rho = \frac{m}{V}. \]

Fig. 1. Thermocouples layout in mold:
1 – mold; 2 – casting part; 3 – pouring basin; 4 – central thermocouple; 5 – chromel-alumel thermocouples.
where \( m \) — mass of cladded mixture; \( V \) — volume occupied by cladded mixture.

BrA9Zh3L bronze samples microstructure investigations have been carried out on optical microscope Neophot-21 after their chemical etching in 0.5 % hydrochloric acid aqueous solution. For microstructure investigation, specimens of \( \Theta 16 \times 130 \) mm have been used, which have been poured into steel chill mold, as well as into SSSM structured according to SMS-process.

Specific heat of structured mixtures \((c_3)\) has been calculated by formula

\[
c_3 = \frac{R_d \rho (n+1)}{2X_0 \rho X_1} \left( 1 + \frac{1}{n+2} \right) \left( X_1^2 \right)
\]

where \( R \) — radius of casting; \( X_1 \) — depth of heat penetration into mold body; \( \rho_1 \) — alloy specific density in solid state; \( \vartheta_{ET} \) — metal overheating excess temperature.

Structured mixtures thermal conductivity has been calculated by formula

\[
\lambda_2 = \frac{R^2 (n+2)}{4n \vartheta_{ET}} \left\{ \frac{(n+2)\rho c_p}{3(n+1)} \left[ 1 + \frac{1}{n+2} \frac{\rho c_p}{\rho c_p + \rho c_2} \right] - 1 \right\}
\]

Calculated value of integral-effective thermal conductivity coefficient has been used for temperature drop in casting determination, and correction has been carried out for values of \( \vartheta_{ET} \) and \( r \) changing.

Coefficient of mold heat storage capacity \((b_1)\) has been calculated by formula

\[
b_1 = \sqrt{\lambda_2 c_2 \rho_2}
\]

and thermal diffusivity \((a_3)\) has been calculated by formula, \( m^2/s \)

\[
a_3 = \frac{\lambda_2}{c_2 \rho_2}
\]

Thermo-physical parameters values of alloys and their melts overheating during pouring into molds adopted for calculations are given in Table 3.

**Results.** In accordance with accepted research methodology, each cylindrical casting has been thermographed and temperature fields’ distributions in molds have been plotted by the time of their solidification completion. As an example, in Fig. 2, a shows thermogram of cylindrical casting made of Al + Mg alloy \((8.5 \%)\) and temperature distribution in SSSM wall \((\text{Fig. 2, } b)\) structured by SMS method with \(3 \% \) SSS.

From thermogram (Fig. 2, a) it follows that heat removal duration of superheat from melt into mold was \(\approx 80 \) s.

**Table 3**

| Alloy          | \( t_s, ^\circ C \) | \( t_f, ^\circ C \) | \( \rho, \text{kg/m}^3 \) | \( c_1, \text{J/kg×deg} \) | \( c_2, \text{J/kg×deg} \) | \( \vartheta_{mSSS}, ^\circ C \) | \( r, \text{J/kg} \) | \( \lambda_{ET}, \text{W/m×deg} \) |
|---------------|---------------------|---------------------|---------------------------|-----------------------------|-----------------------------|-----------------------------|-------------------|-----------------------------|
| Al – Mg \((8.5 \%)\) | 623                 | 540                 | 2635                      | 950                         | 1160                        | 372                         | 73                | 80                          |
| SCh 200       | 1200                | 1150                | 7100                      | 560                         | 840                         | 263                         | 80                |                             |

*Note: \( c_1 \) — liquid metal specific heat*

![Fig. 2. Thermogram of cylindrical casting made of Al + Mg alloy \((8.5 \%)\) solidification \((a)\) and temperature distribution in SSSM mold wall \((b)\) structured by SMS method](image)

**Fig. 2.** Thermogram of cylindrical casting made of Al + Mg alloy \((8.5 \%)\) solidification \((a)\) and temperature distribution in SSSM mold wall \((b)\) structured by SMS method.

Using thermocouples readings and data on their distance from casting surface, temperature distribution curve in form has been built (Fig. 2, b). Mold working surface temperature values \((t_{surf})\) and depth of mold heating \((X_2)\) have been determined from results of temperature distribution curve in the mold extrapolation.

Parabola degree \((m)\) has been calculated as ratio of image area above \((S_2)\) and below \((S_1)\) temperature curve. Images areas have been determined from results of their planimetry.

Calculated and experimental parameters values, adopted for computation by formulas (3—6), of thermo-physical properties integral-effective characteristics for structured mixtures, when pouring Al + 8.5 % Mg alloy and gray cast iron SCh 200 into them, are given in Table 4.

Calculating results of structured mixtures thermo-physical properties integral-effective values are given in Tables 5 and 6. According to Tables 5 and 6 data, dependences \( b_2 = f(m_{SSS}) \) (Fig. 3, a) and \( t_{SSS} = f(t_{SSS}) \) (Fig. 3, b) for semi-infinite castings \( \Theta 30 \) mm have been plotted.

Thermal conductivity and specific heat dependences on apparent density of casting molds material are shown in Fig. 4. Molds integral-effective thermal diffusivity and heat storage capacity dependences on apparent density of its material are shown in Fig. 5.

Mold material heat storage capacity integral-effective co-efficient dependences on mass of SSS \((mSSS)\) used for cladding are shown in Fig. 6, a. Semi-infinite cylindrical casting \( \Theta 30 \) mm solidification duration dependences on mold material heat storage capacity coefficient value are shown in Fig. 6, b.
Curves of dependences \( \tau_{SOL} = f(b_2) \), shows in Fig. 6, \( b \). Plots in Fig. 6, \( b \) analysis shows that both functions agree with formula (2) in terms of casting solidification duration dependence on \( b_2 \) value.

Let us represent formula (2) in following form

\[
\tau_{SOL} = B \left( \frac{R}{b_2} \right)^2 ;
\]

\[
B = \frac{n+1}{2n} \left[ \frac{\rho_{2,0} \cdot r}{(R_{KT} - R_M)} \right]^2 .
\]

Using formula (7) at \( B = 84 \cdot 10^6 (W \cdot s)^2/(m^4 \cdot \deg^2) \) for aluminum alloy and \( B = 10^2 \cdot 10^6 (W \cdot s)^2/(m^4 \cdot \deg^2) \) for gray cast iron with relative error no more than 5 %, solidification time of semi-infinite cylindrical casting in SSSM, structured by SMS-process, can be calculated. It has been evidenced by Table 7 data, which shows error (\( \Delta t \)) values between calculated and experimental values of castings solidification duration.

For data obtained practical using, most acceptable is dependence of structured molding mixture solidification time on specific gravity, shown in Fig. 7, \( a \).

It should be taken into account that structured SSSM by SMS method apparent density value also depends on cladded sand particles conglomerates size (dPCS), as evidenced by dependence in Fig. 7, \( b \). Dependence in Fig. 7, \( b \) analysis shows that, with pure sand apparent density of 1642 kg/m \(^3\), sand-sodium-silicate conglomerates size increasing from 0.1 to 0.8 mm leads to structured mixture apparent density in 2-time decreasing – from \( \sim 1610 \) to \( \sim 810 \) kg/m \(^3\). Accordingly, such changes will lead to change in thermo-physical properties of structured mixture. That is, by SSS mass changing in cladded sand or using different sand-sodium-silicate mixture conglomerates fractions, it...
is possible to predictably change casting solidification time and, accordingly, alloy structure. This, in particular, is evidenced by microstructures of BrА9Zh3L bronze castings, prepared in various molds, and presented in Fig. 8, and by data in Table 8.

Conclusions. For the first time, the thermo-physical properties integral-effective values of quartz sand cladded with sodium silicate solute in amount of 0.5 to 3.0 % (by weight, in excess of 100 % quartz sand) and structured by SMS method when pouring aluminum-magnesium alloy and gray cast iron into it have been determined.

Table 7

| Casting mold | Steel chill mold |
|--------------|------------------|
| SSSM, fabricated by SMS-process with SSS content – 0.5 % (b), 1.0 % (c), 1.5 % (d) and 2.5 % (e) |

Table 8

| Casting mold | Steel chill mold |
|--------------|------------------|
| SSSM, fabricated by SMS-process with weight SSS content |
| 0.5 % | 1 % | 1.5 % | 2.5 % |
| D, μm | 0.12 | 0.33 | 0.41 | 0.50 | 0.73 |

Fig. 5. Dependences of $a_2$ (a) and $b_2$ (b) on structured mixture apparent density:
1 – castings from alloy Al + 8.5 % Mg; 2 – castings from gray cast iron SCh 200

Fig. 6. Dependences $b_2 = f(m_{SSS})$ (a) and $\tau_{SOL} = f(b_2)$ (b):
1 – castings from alloy Al + 8.5 % Mg; 2 – castings from gray cast iron SCh 200

Fig. 7. Dependences $\tau_{SOL} = f(p_2)$ (a) and $p_2 = f(d_{PCS})$ (b):
1 – castings from alloy Al + 8.5 % Mg; 2 – castings from gray cast iron SCh 200

Fig. 8. Specimen $\varnothing16 \times 100$ mm of BrА9Zh3L bronze microstructure ($\times100$) cast into steel chill mold (a) and SSSM, manufactured by SMS-process with SSS content – 0.5 % (b), 1.0 % (c), 1.5 % (d) and 2.5 % (e)
Високотемпературні властивості піщано-рідкоскляних сумішей після їх структурування в паро-мікрохвильовому середовищі

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Мета. Визначити інтегрально-ефективні значення теплофізичних властивостей піщано-рідкоскляних сумішей після їх структурування, при заливці в них сплаву Al-Mg і сірого вугілля, що є основними матеріалами при виготовленні виплавок із дрібнозернистою мікроструктурою. При цьому вони мають щільність середньою 0,64-0,86 г/см3, уявну щільність 0,59-0,77 г/см3, середні значення теплоемності 0,61-0,85 кДж/г·К і теплоізоляційного коефіцієнту 0,13-0,19 м2·К/Вт·К.

Замовлення. Встановлено, що збільшення кількості рідкоскляного компоненту до 25 % в паро-мікрохвильовому середовищі при заливці в них сплаву Al-Mg і сірого вугілля призводить до збільшення їх власного коефіцієнту теплопровідності на 30 і 35 % відносно до паро-мікрохвильових виплавок, при заливці в них сплаву Al-Mg і сірого вугілля.

Практична значимість. Використання отриманих даних дозволить підвищити точність аналітичних розрахунків часу та швидкості затвердіння виплавок, прогнозу рівня й знака в них залишкових напружень, місця розташування ускладнів, що скоротить час і витрати на відправлення виплавок.

Ключові слова: піщано-рідкоскляна суміш, паро-мікрохвильове затвердіння, теплофізичні властивості, виливки, мікроструктура

The manuscript was submitted 29.04.21.

ISSN 2071-2227, E-ISSN 2223-2362, Науковий вісник Национального Харківського університету, 2021, № 6 71