UDC 004.942, 621.746.6.001.2

CALCULATION SCHEMES AND INFORMATION TECHNOLOGY FOR DETERMINATION OF TECHNICAL PARAMETERS GAS-DYNAMIC EFFECT ON THE MELT IN THE MOLD

Selivorstov V., Selivorstova T.

Приведено описание общей методики определения технологических параметров для реализации газодинамического воздействия при производстве отливок и слитков, а также схемы расчета динамики изменения газового давления. Представлены применяющиеся оригинальные и известные расчетные схемы и программные продукты.

Ключевые слова: технологические параметры, расчет, затвердевание, герметизация, температурное поле, моделирование, режим газодинамического воздействия, компьютерная программа.

Приведений опис загальної методики визначення технологічних параметрів для реалізації газодинамічного впливу при виробництві виливків і зливків, а також схеми розрахунку динаміки зміни газового тиску. Представлені оригінальні та відомі розрахункові схеми і програмні продукти, що були використані.

Ключові слова: технологічні параметри, розрахунок, затвердіння, герметизація, температурне поле, моделювання, режим газодинамічного впливу, компьютерна програма.

The article describes General methods for determining the technological parameters for the implementation of gas-dynamic influence in the production of castings and ingots, as well as the scheme for calculating the dynamics of change in gas pressure. Used presents an original and well-known calculation schemes and software products.

Keywords: technological parameters, calculation, solidification, sealing, temperature field, modeling, mode of gas-dynamic influence, computer application.

Introduction. One way to improve the quality of cast metal is the use of pressure during crystallization. It is known that the most effective is transmission of increasing pressure to two-phase zone, especially in the late period of solidification. With existing methods of such casting much of the stress associated with used pressure is implemented by the strength of mold or containers in which it is set, which significantly limits the possible range of pressure and mass of castings. These features are included in the technological process developed at the Department of foundry National Metallurgical Academy of Ukraine that provides gas pressure on the alloy inside the casting to complete its consolidation, particularly under conditions of metal self-sealing the mold.

Analysis of previous publications. The developed casting method can be used for different alloys and molds [1-5] on condition of adequate device construction is used [6,7]. During the technology use the gas-dynamic effect on the alloy inside the casting begins after an indurated superficial layer appears and its thickness is enough to withstand the pressure transmitted by special device right after the sealing "casting- gas injection device" system in the mold is completed. The dynamic of pressure changes in "casting-gas injection device" is determined by changes of superficial indurated layer strength characteristics, that increase in proportion to the distance from casting surface [8]. A value, close to indurated superficial layer ultimate stress limit (σ_B) with equate temperature [9,10] and with regard to relative extension, that appears in the indurated layer and depends on casting configuration and size, can be used as maximum possible pressure (MPa) in a moment. In the process of growing tension in the crust during the entire process of induration is supported nearly at peak, prior to destruction. This approach is used in terms of the metal mold and can achieve maximum results in terms of cast metal quality (especially mechanical properties), but leads to deformation of the casting because of alloy relative extension. With the stability of the geometric dimensions of the casting, that indurates in block mold or a single-use sand molds the casting material deformation resistance (σ) in the range of operating temperatures is used as the parameter to calculate the dynamics of pressure rise in the "casting- gas injection device".

While determining the technological process parameters there is need to choose appropriate sealing refrigerator construction parameters and, in the case of combined refrigerator - material and size of the insulating insert, set basic temperature and time settings for system “casting-gas injection device” sealing with regard to weight and size change of casting and mold [11 - 14] and calculate gas-dynamic impact exercise regime [15, 16]. The implementation of the above-mentioned procedures in practice requires the use of specially designed methods of calculation and software schemes hence systematic review of them seems a valid task.

The aim is to present a set of software and information technology that provides the estimated gas-dynamic effect on the alloy in the mold.

Baseline. To calculate the technological parameters of developed the process known and used original settlement schemes and information technology were used (Fig. 1).

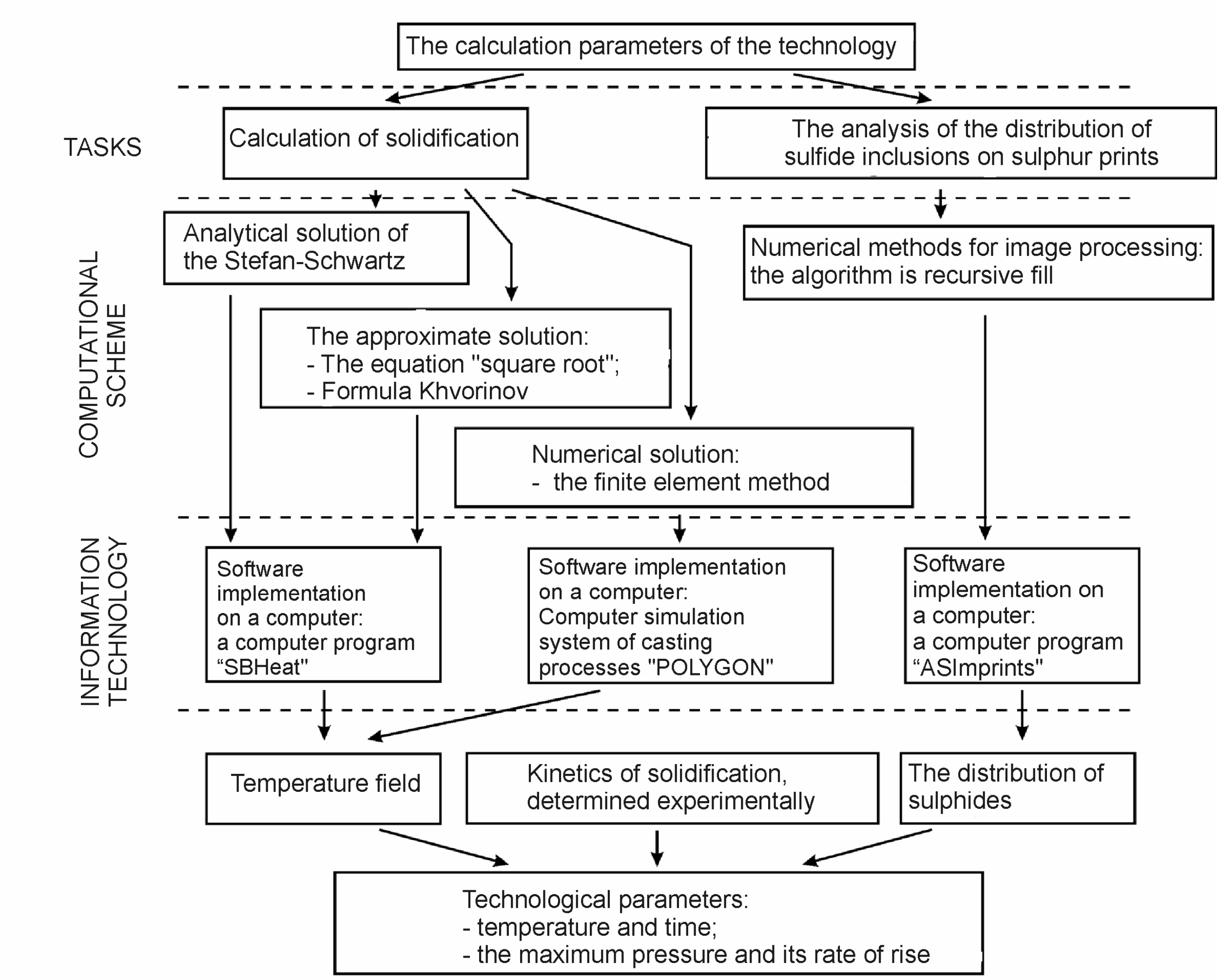

Fig. 1. Diagram illustrating a general method for determining the process parameters for steel casting as an example

The software module «SBHeat», which is designed to calculate the temperature fields of casting and mold be Stephen Schwartz method, has an intuitive interface and can be used in Windows. Module testing has shown promising use of this software on condition of finding rational technological modes of casting processes conduction [17, 18].

The developed software package (PC) «ASImprints» provides: preliminary image procession of sulfur print by translation from grayscale to monochrome in accordance with the set binarization threshold; determination of impurities belonging to a certain range and filled with color coded according to the specified size ranges; obtaining statistical dataabout the number of particles of a certain size, and the size of the particles is provided in pixels and square millimeters [19, 21].

Setting temperature-time parameters for casting mold sealing is prerequisite for implementation of gas-dynamic effects. It is possible to define the formation time of metal sealing layer by using thermoelectric experimental studies, computer simulation of casting processes (SCM LP) and engineering methods for calculating the temperature field of casting [18].

Comparison of the results of calculations for process of hardening in sand bulk form balls and a cylinder diameter of 200 mm and a plate 200 mm thick carbon steel and aluminum eutectic alloy by finite element method and engineering Stefan Schwarz method was held. The value of the maximum relative deviation of temperature distribution (1) obtained as the results of calculations by various methods (Table. 1) demonstrate that the use of analytical decision-Stephen Schwartz for building the casting temperature field is reasonable [22].

$$\Delta = \max_{i=1,\dots n}\left\{\frac{\left|T_{i1}-T_{i2}\right|}{\left(T_{i1}+T_{i2}\right)/2}100\%\right\} \qquad (1)$$

where T_{i1} - the temperature in the i -the point obtained using engineering calculation Stefan - Schwarz via software module «SBHeat», T_{i2} - the temperature in the i -the point obtained using SCM LP "Polygon".

Table 1

The comparison of the calculation results of solidification of castings of various configurations of the engineering method and the finite element method

Casting material	Maximum relative deviation (%) isochrone during the solidification of the parts are given thickness of the casting								Deviation time curing, %
	for a cast, x/X				for a mould, x/X				
	0,1	0,5	0,9	1	0,1	0,5	0,9	1	
ball									
Aluminum alloy	0,8	0,6	0,2	0,8	10,2	40,7	41,4	41,6	1,6
Carbon steel	0,2	0,9	1,5	1,9	13,8	45,8	45,9	46,3	0,5
Cylinder									
Aluminum alloy	1,1	0,5	0,2	0,1	26,2	34,8	34,9	34,8	1,9
Carbon steel	0,2	0,7	0,7	0,9	5,5	41,2	40,9	41,6	2,6
Plate									
Aluminum alloy	0,8	0,5	0,3	0,2	9,4	1,3	0,8	0,8	1,8
Carbon steel	1,9	0,3	0,2	0,2	17,1	2,9	0,9	0,7	1,4

When casting a block mold traditional formulation of the Stefan Schwarz problem is not applicable because the layer of paint on the surface of the mold can be taken into account only indirectly by the coefficient of induration and the coefficient of mold heat accumulation definition of which can be got by changing the thickness of the paint experimentally, but in practice this is very difficult and leads to unnecessary complications and the need to implement cumbersome calculation algorithms. Therefore, developed combined calculation scheme, carried out as follows. According to AI techniques Veynyka the induration time for casting in painted block mold is calculated (2, 6), that determines the coefficient of hardening (10) taking into account the thickness of the paint layer (3). Then the formula MI

Hvorinova heat accumulation coefficient is calculated (11) and temperature fields are calculated by the method of Stephen Schwartz, (12 - 15).

$$\tau_{пер} = \frac{V_1 \rho_L c_L \left(T_1 - T_L\right)}{\beta F_1 \left(T_1 - T'_{2ср}\right)}, \tag{2}$$

$$\beta = \frac{\lambda_{кр}}{\chi_{кр}}, \tag{3}$$

$$T'_{2ср} = \frac{T'_{2n} + T'_{2к}}{2}, \tag{4}$$

$$T'_{2к} = \frac{V_2 \rho_F c_F T'_{2n} + V_1 \rho_L c_L \left(T_1 - T_L\right)}{V_2 \rho_F c_F}, \tag{5}$$

$$\tau_{затв} = \frac{V_1 \rho_L \left(c_{ср} \Delta T_{кр} + L\right)}{\beta F_1 \left(T_L - T''_{2ср}\right)}, \tag{6}$$

$$T''_{2ср} = \frac{T'_{2к} + T''_{2к}}{2}, \tag{7}$$

$$T''_{2к} = \frac{V_2 \rho_F T'_{2к} + V_1 \rho_L c_{еф} \left(T_L - T_S\right)}{V_2 \rho_F c_F}, \tag{8}$$

$$c_{еф} = c_{ср} + \frac{L}{\Delta T_{кр}}, \tag{9}$$

where $T''_{2к}$ - the average temperature across the section of wall metal mold during solidification of the casting, K; T''_{2cp} - the average temperature across the section of block mold wall in the late stages of casting induration, K; $c_{еф}$ - effective heat capacity of the material casting, J/kg; L - heat of crystallization of alloy , J/kg; ΔTkr - crystallization temperature range, K; V - volume, m^3; F - surface area m^2; ρ - density, kg/m^3. The indices 1 and 2 stand for the values relating proportionally to the casting or block mold.

$$K = \frac{x}{\sqrt{\tau_{затв} + \tau_{пер}}}, \tag{10}$$

$$b_F = \frac{K \rho_L \left(L + c_L \left(T_1 - T_0\right)\right)}{1{,}158 \left(T_0 - T_{F_0}\right)}, \tag{11}$$

$$T_C = \frac{T_O}{1 + \frac{b_F}{b_S} erf\left(\frac{K}{2\sqrt{a_S}}\right)} \tag{12}$$

$$T_L = \left(T_O + t\right) - t \frac{1 - erf\left(\frac{y}{2\sqrt{a_L \tau}}\right)}{1 - erf\left(\frac{K}{2\sqrt{a_L}}\right)} \tag{13}$$

$$T_S = T_C + \left(T_O - T_C\right)\frac{erf\left(\dfrac{y}{2\sqrt{a_S\tau}}\right)}{erf\left(\dfrac{K}{2\sqrt{a_S}}\right)} \quad (14)$$

$$T_F = T_C - \left(T_O - T_{F_0}\right)erf\left(\frac{y}{2\sqrt{a_F\tau}}\right) \quad (15)$$

where K - coefficient of hardening, $м/c^{0,5}$; T_C - temperature at the point of casting and mold collision, K; a - heat capacity, $м^2/c$; b_F - coefficient of form heat accumulation $Bm\ c^{0,5}/м^2\ K$.. The S and L stand for the values relating respectively to solid or liquid casting parts, F - to the form.

The calculation results of shaped casting induration time in block mold " Rack conveyor supporting tip " weighing 1.1 kg alloy AK5M (Fig. 2) finite element method (FEM) and by Stephen Schwartz method, showed the need to consider a layer of paint in casting and efficiency of the developed combined scheme (Table. 2).

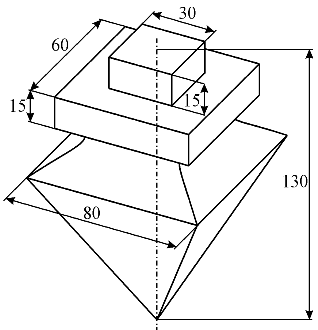

Fig. 2. Scheme of casting "tip rack conveyor"

Table 2

The calculated solidification time of the casting

The share of the given thickness, x/X	Curing time, *c*		
	Stefan-Schwartz		finite element method
	excluding the layer of paint	taking into account the layer of paint	
0,1	0,3	6,1	7
0,3	0,6	13,8	16
0,5	1,8	38,3	40
1,0	7,3	153,1	157

Calculation of gas-dynamic impact includes pre-processing and obtaining initial data, performance of calculation algorithm and further results analysis (Fig. 3) [23, 24].

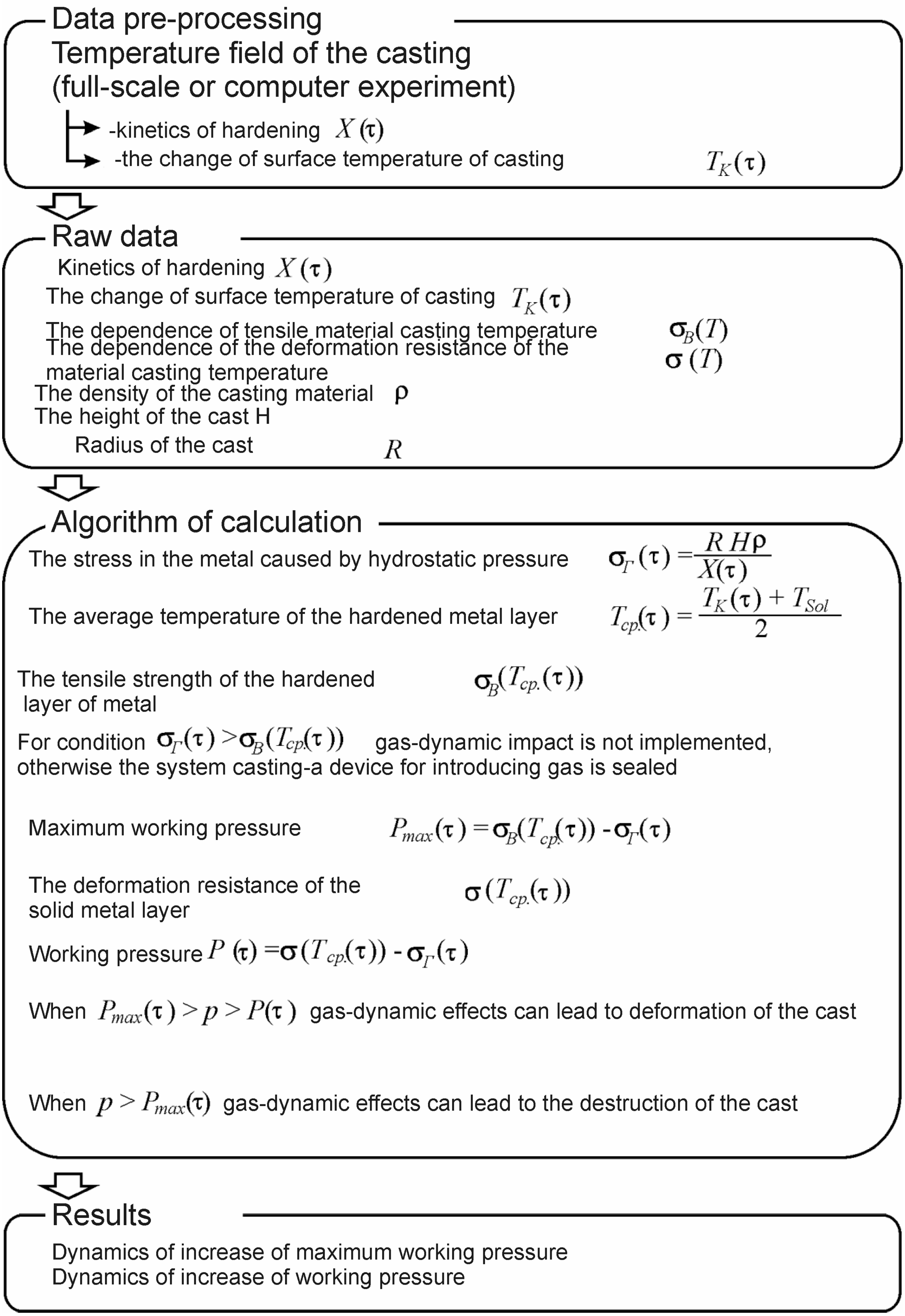

Fig. 3. Calculation scheme of gas-dynamic mode impact

The initial step is the preprocessing of data. It is to determine the kinetics of casting induration X (τ) and its surface temperature change TC (τ). There is also a need to build the casting temperature field on the basis of thermographic investigations or calculations. Initial data also depends on ultimate tensile strength temperature and deformation resistance, also casting material density and its geometrical characteristics (for cylindrical casting - height and radius).

On next step (calculation algorithm) the dynamic of maximum working pressure growth P max (τ) and the dynamic of working pressure growth P (τ) are calculated. During casting induration the average temperature of hardened layer T (τ) changes, proportionally to σ_B value and σ, which allows to calculate dynamics of working pressure. The magnitude and dynamics of maximum working pressure change were calculated as the difference between the values of ultimate tensile strength and tensile stress values (σ) in the indurated layer of metal, in accordance to the working pressure - the difference between the values of deformation resistance and tensile stresses values.

For automatic mode of gas-dynamic effects determination (Fig. 4) computer program «GDICalc» was developed (Gas-Dynamic Influence Calculation) [25].

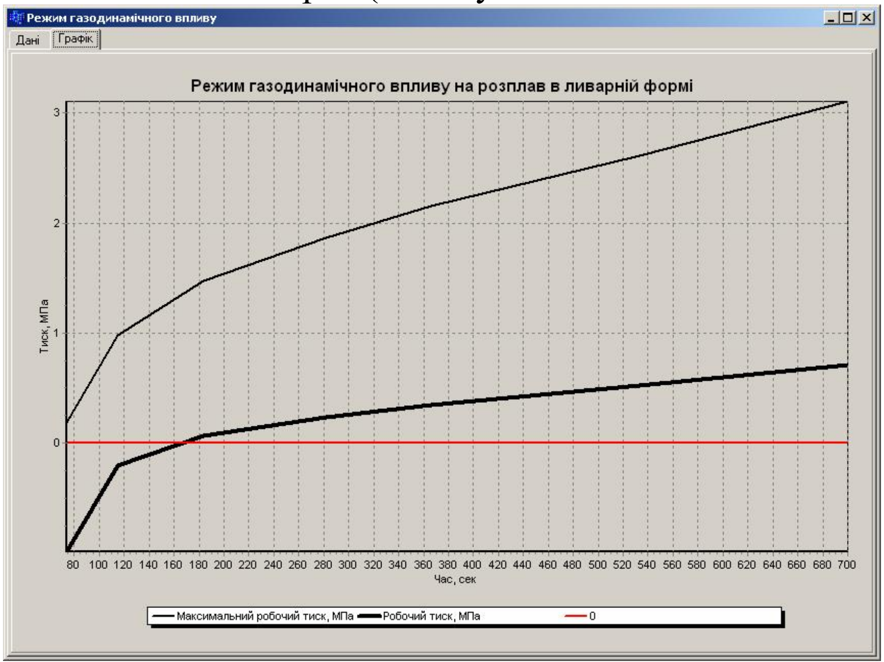

Fig. 4. GDICalc interface, dialog box "gas-dynamic influence mode " tab "Charts"

Conclusions

1. The developed combined calculation method of technological parameters of gas-dynamic effect on the liquid phase in the casting is based on compliance of pressure increase in system “casting-gas injection device” dynamics to casting induration kinetics. It was established that the main limitation of the pressure usage range is dependence of casting material strength properties on temperature. The technique allows to formalize the realization and gas-dynamic effects mode choice

conditions, and can be implemented by using a developed computer program «GDICalc».

2. A combined calculating scheme of casting temperature fields, including the induration timing of casting painted in the uncooled mold blocks method according to Veynyk with the use of hardening coefficient, that takes into account the thickness and thermal properties of paint layer and heat accumulation coefficient calculation according to Hvorinov formula and temperature fields by Stefan - Schwarz method. The use of advanced analytical solutions allows considering the thickness and thermal properties of casting paint on the surface of uncooled metal mold while calculating casting induration timing correctly.

3. In case of diversifying calculation methods of time-temperature casting sealing parameters in bulk sand form is needed, it is set reasonable to use analytical Stephen Schwartz decision for the temperature fields construction, particularly in the form of developed software module «SBHeat».

References

1. Селиверстов В.Ю. Технология газодинамического воздействия на расплав в литейной форме – один из перспективных способов повышения качества металла отливок // Сучасні проблеми металургії. Наукові праці. 2007. – Том 10. – С. 25 – 35.
2. Пат. 28858 Україна, МПК (2006) B22D 18/00. Спосіб отримання виливків / Селівьорстов В.Ю., Хричиков В.Є., Доценко Ю.В. – № 200708968; заявл.03.08.2007; опубл. 25.12.2007, Бюл.№21.
3. Пат. 37838 Україна, МПК (2006) B22D 18/00. Спосіб отримання виливків / Селівьорстов В.Ю., Хричиков В.Є., Доценко Ю.В. – № 200808859; заявл.07.07.2008; опубл. 10.12.2008, Бюл.№23.
4. Пат. 46128 Україна, МПК (2009) B22D 18/00. Спосіб отримання виливків / Селівьорстов В.Ю., Хричиков В.Є., Куцова В.З., Меняйло О.В., Савега Д.О. – № u 200906107; заявл.15.06.2009; опубл. 10.12.2009, Бюл. №23.
5. Пат. 55301 Україна, МПК (2009) B22D 18/00. Спосіб отримання виливків /Селівьорстов В.Ю., Хричиков В.Є., Доценко Ю.В., Кущ П.Д., Савега Д.О.; власник патенту Національна металургійна академія України – № u 201006702; заявл. 31.05.2010; опубл. 10.12.2010, Бюл. № 23.
6. Пат. 28859 Україна, МПК (2006) B22D 18/00. Пристрій для отримання виливків / Селівьорстов В.Ю., Хричиков В.Є., Доценко Ю.В. – № 200708969; заявл.03.08.2007; опубл. 25.12.2007, Бюл.№21.
7. Пат. 37837 Україна, МПК (2006) B22D 18/00. Пристрій для отримання виливків / Селівьорстов В.Ю., Хричиков В.Є., Доценко Ю.В. – № 200808858; заявл. 07.07.2008; опубл. 10.12.2008, Бюл.№23.
8. Селівьорстов В.Ю. Особливості розрахунку газодинамічного впливу на метал, що твердіє в кокілі [Текст] / В.Ю. Селівьорстов // Теорія і практика металургії. – 2009. - № 1-2. – С. 41 – 45.
9. Селиверстов В.Ю. Особенности расчета температурного поля отливки из сплава АК5М, затвердевающей в окрашенном чугунном кокиле [Текст]/

В.Ю. Селиверстов // Теория и практика металлургии. – 2008. - № 5-6. – С. 32 - 36.

10. Третьяков А.В. Механические свойства металлов и сплавов при обработке давлением: Справочник [Текст] / А.В. Третьяков, В.И. Зюзин // М.: Металлургия, 1973. – 224 с.
11. Селиверстов В.Ю. Влияние наружного холодильника на процесс герметизации отливки из стали с широким температурным интервалом затвердевания в кокиле // Теория и практика металлургии. – 2008. - № 3. - С. 32-37.
12. Селиверстов В.Ю. Особенности герметизации отливки из углеродистой стали, затвердевающей в кокиле, при изменении конструкции и размеров наружного холодильника /В.Ю. Селиверстов //Теория и практика металлургии. – 2010. – № 3 – 4. – С. 26 – 30.
13. Селиверстов В.Ю. Влияние конструктивних особенностей и материала наружного холодильника на процесс герметизации в кокиле отливки из штамповой инструментальной стали /В.Ю. Селиверстов //Восточно-Европейский журнал передовых технологий. – 2010. – № 4/5 (46). – С. 42 – 46.
14. Селиверстов В.Ю. Особенности процесса герметизации отливки в форме ЛВМ для осуществления газодинамического воздействия /В.Ю. Селиверстов, П.Д. Кущ //Теория и практика металлургии. – 2010. – № 5 – 6. – С. 95 – 98
15. Селівьорстов В.Ю. Особливості розрахунку газодинамічного впливу на метал, що твердіє в кокілі // Теорія і практика металургії. – 2009. - № 1-2. – С. 41 - 45.
16. Селиверстов В.Ю. Особенности расчета режима газодинамического воздействия на расплав при кристаллизации отливок из сталей 35Л, Х18Ф1 и алюминиевого сплава АК5М в металлической форме /В.Ю. Селиверстов //Теория и практика металлургии. – 2010. – № 1 – 2. – С. 64 – 67.
17. . Комп’ютерна програма «SBHeat-Інженерний розрахунок температурного поля напівобмеженого виливка»; свідоцтво про реєстрацію авторського права на твір № 22135 / Михайловська Т.В., Селівьорстов В.Ю.; дата реєстрації 21.09.2007.
18. Михайловская Т.В., Селиверстов В.Ю. Компьютерный расчет температурного поля отливки и объемной песчаной формы для управления технологическими режимами // Вестник СевГТУ: Сб. науч. тр. / МОН Украины. Севастоп. нац. техн. ун-т. Вып 95: Автоматизация процессов и управления – Севастополь: Изд-во СевНТУ, 2009. – С. 47-52.
19. Комп’ютерна програма “ASImprints – Аналіз сірчаних відбитків” Селівьорстов В.Ю., Михайловська Т.В. // Свідоцтво на твір № 28879 від 25.05.2009 р.
20. Михайловская Т.В., Селиверстов В.Ю. Компьютерная обработка серных отпечатков темплетов отливок на основе алгоритма рекурсивной заливки // Нові технології. – 2009. - №2. – С. 26 – 30.

21. Селиверстов В.Ю., Михайловская Т.В., Доценко Ю.В., Мушенков Ю.А. Влияние газодинамического воздействия на распределение сульфидных включений в цилиндрической отливке из углеродистой стали, затвердевающей в кокиле // Металлургическая и горнорудная промышленность. – 2009. - №5. - С. 40 – 43.
22. Селиверстов В.Ю. Инженерный расчет температурного поля отливки для процесса газодинамического воздействия на расплав в литейной форме // Металлургическая и горнорудная промышленность. – 2008. - №6. - С. 31 – 34.
23. Селиверстов В.Ю. Методика расчета параметров газодинамического воздействия на затвердевающий металл в литейной форме / В.Ю. Селиверстов, Т.В. Михайловская //Системні технології: Регіональний міжвузівський збірник наукових праць. – Дніпропетровьк, 2010. – Вип. 3 (68). – С. 186 – 192.
24. «Методика розрахунку режиму газодинамічного впливу на розплав в ливарній формі»; свідоцтво про реєстрацію авторського права на твір /Селівьорстов В.Ю. – № 34833; дата реєстрації 06.09.2010.
25. Комп’ютерна програма «GDICalc»; свідоцтво про реєстрацію авторського права на твір /Селівьорстов В.Ю., Михайловська Т.В. – № 34834; дата реєстрації 06.09.2010.