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Strain of Casting Patterns in the Investment Casting

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Abstract

The cause of casting pattern strain in the investment casting is detected. The suggestions upon increase in accuracy of casting patterns mould are specified.

Keywords: *strain, casting pattern, mould, coefficient, shrinkage, stress*

Statement of the problem

Manufacture of castings with no strain is of great importance, first of all, for thin-walled special-purpose castings made of brittle alloys by investment casting method. Casting strain is caused mainly by strain of casting patterns. Hence, the problem related to increase in accuracy of any casting mould should be primarily solved by increasing accuracy of casting patterns mould.

Today, all the knowledge about casting strain in the investment casting have a fragmentary character and do not allow getting an insight into both casting pattern strain mechanism and main reasons for this.

The purpose of present research is to detect the major reasons for strain in investment patterns of castings.

Main research results

The tests were carried out on casting patterns (CP) made by means of free pouring of melt containing wax-like pattern material in a steel mould so that it was possible to eliminate the effect of parameters of pattern material pressing in the mould (die mould) upon strain value of CP. The roughness value of working surfaces of the mould applied is Ra 0.63. The mould temperature at the moment of its filling with the melt was the same as ambient temperature 24±1 °C. The working surfaces of the mould before each pouring were lubricated with polymethyl-siloxane liquid of grade PMS-100.

CP were made of materials with crystalline structure (paraffin of grade ParK2/1, oil ceresin of grade 95), materials with mixed structure (brown-coal wax of grade Romonta Y-S80, polyethylene wax of grade PV-200), materials with amorphous structure (glycerine-rosin ether of highest grade) as well as of alloys, the composition of which is presented in Table.

**Table. Composition of pattern alloys**

Material	Materials content in the alloy, wt.%						
	1	2	3	4	5	6	7
Paraffin	70	65				95	
Ceresin of grade 80		15					
Ceresin of grade 75				28	14		20
Glycerine-rosin ether			80	66	76		80
Polyethylene wax	10		20	6	10		
Brown-coal wax	20	20					
Polypropylene						5	

The strain value (Δ_s) was determined using a CP of beam-type and T-section (Figure 1) as a distance between point A and point C according to the scheme presented in Figure 2. Strain was measured by monocular microscope of 0.1 mm division value, and was recorded with a "minus" sign, if deflection of CP was concave (Figure 2a). Respectively, at return deflection of CP (convexity) the value Δ_s was recorded with a "plus" sign (Figure 2b). Before measurement, the CP was in the air at 24±1 °C during 24-26 hours starting from the moment of its removal from the mould.

In this research, there are used CP with one (Figure 1a) and two (Figure 1b) crosswise flanges that enabled formation of CP during its cooling in the mould to room temperature under conditions of conditionally free and absolutely hindered shrinkage, respectively. According to methodology, the value of CP strain was determined by its
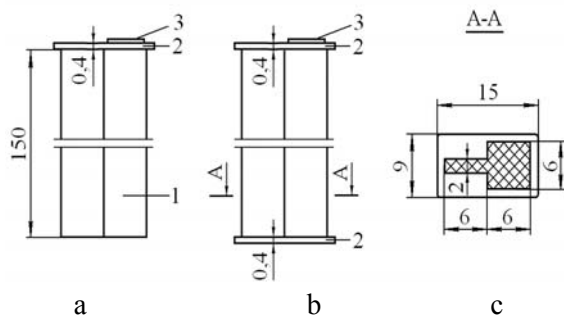
Figure 1. Casting pattern (CP) of beam-type and T-section for solidification under conditions of free (a) and absolutely hindered (b) shrinkage: 1 – CP; 2 – flange; 3 – header place
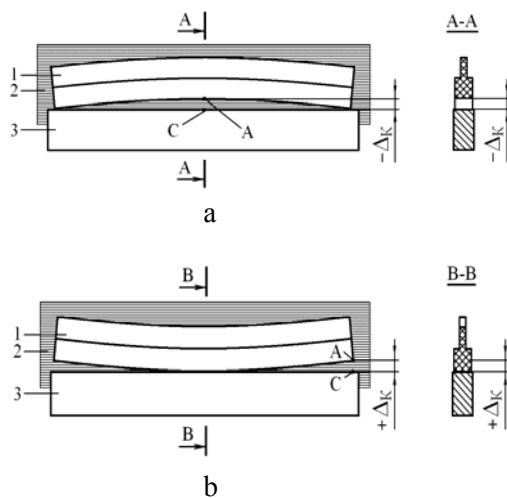
Figure 2. Scheme for determination of CP strain value: 1- CP; 2 – scale; 3 – support

cooling period in the mould (starting from the end moment of mould casting) under conditionally free and absolutely hindered shrinkage. The results of research are presented in Figures 3-6.

The analysis of functions presented in Figure 3 shows that as soaking time (solidification) of CP in the mould under conditionally free shrinkage increases, the value of CP strain (concavity) decreases and can be expressed as a first approximation by the following formula:

$$\left| -\Delta_s \right| = (1 - A \cdot \tau)^n \cdot B \ , \qquad \text{(Eq.1)}$$

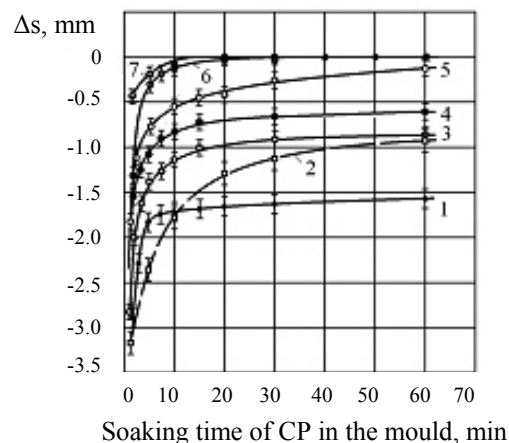where A - the coefficient, c^{-1};

τ – the soaking time of CP in the mould, sec;
n – the degree index;
B – the coefficient, min.

In accordance with Equation (1) and functions in Figure 3, the early removal of CP from the mould is inadmissible from the point of view of

Figure 3. The value of CP strain as a function of its soaking time in the mould under conditions of free shrinkage: 1 – polypropylene wax PV-200; 2 – brown-coal wax Romonta Y- S80; 3 – alloy No.1; 4 –alloy No. 2; 5 – oil ceresin of grade 95; 6 – paraffin ParpK2/1; 7 – glycerine-rosin ether

strain prevention. From the same point of view, it is not desirable to use a non-rigid mould, i.e. made of rubber, latex, etc. as well as moulds in which separate parts that contac with CP are made of different materials, i.e. of steel and plastic materials.

The analysis of functions presented in Figure 3 shows that for a range of pattern materials even soaking of CP in the mould during 60 minutes does not allow avoiding strain. At the same time, CP made of paraffin and glycerine-rosin ether in the process of cooling in the mould during more than 30 and 15 minutes respectively have not been strained yet. Thus, in this case there are two approaches. The first approach is that in CP made of above-mentioned materials there are no residual stresses or these stresses are so small that they do not exceed the yield point of CP material and, correspondingly, do not cause its strain. The second approach is that the strain caused by these stresses is so small that it cannot be determined by currently adopted methods of strain measurement. The strain of CP made of paraffin and glycerine-rosin ether when soaking in the mould for less than 30 and 15 minutes respectively is caused by plastic deformation related to temporary (thermal) stresses in CP.

In our point of view, substantial strain of CP made of polyethylene wax and brown-coal wax, alloy No.1, alloy No.2 and glycerine-rosin ether is caused by propagation of temporary stresses

during soaking of CP in the mould for not less than 10-20 minutes. At the same time, the strain of CP made of these materials under their soaking in the mould during more than 10-20 minutes is caused by residual stresses. Probably, the more value of residual stresses, the more strain of CP. In its turn, the value of residual stresses and strain value of CP depend upon termperature of plastic-elastic transformation of CP material. At the same time, the less difference between temperature of plastic-elastic transformation of CP material and temperature of its crystallization, the more the value of residual stresses in solidified CP and its strain value. Thus, the main reason for strain of CP solidified and cooled under conditionally free shrinkage and at early CP removal from the mould is temporal (thermal) stresses and, in case of late removal of CP, residual stresses.

Formation of temporary and residual stresses in CP is accompanied with plastic deformation of pattern material. The pattern material is subjected to plastic deformation during solidification and during initial cooling period of CP in the mould as a result of shrinkage stopping from the side of mould walls and adjacent elements of CP. In the process of CP formation under conditionally free shrinkage, the value of plastic deformation of each element of CP depends upon its nominal sizes and mainly determines the value of their linear shrinkage. In case of castings made of metals and alloys, interrelation of hindered (conditionally free, actual, technological) shrinkage and nominal size of casting is explained by the mould strain under pouring, mechanical and thermal shrinkage stopping. At the same time, resistance of mould and cores affects residual stresses in the same way as this resistance causes non-uniform plastic deformations in the casting under cooling [1].

On the principle that under assumed conditions of CP making, deformation of the mould does not occur, the major cause of stress origination in CP is mechanical and thermal shrinkage stopping. As applied to conditions of CP making by investment casting, the effect of thermal shrinkage stopping upon CP strain can be eliminated by means of increasing duration of cooling period of CP in the mould (to cool CP in the mould to room temperature). In this case, the strain value of CP will be determined exclusively by its residual stresses. As mentioned above, residual stresses in CP are the result of non-uniform plastic deformation of its elements. To determine the period of origination of residual stresses in the

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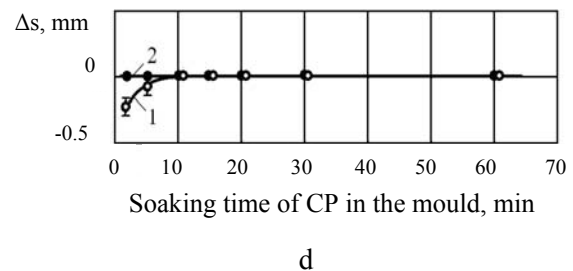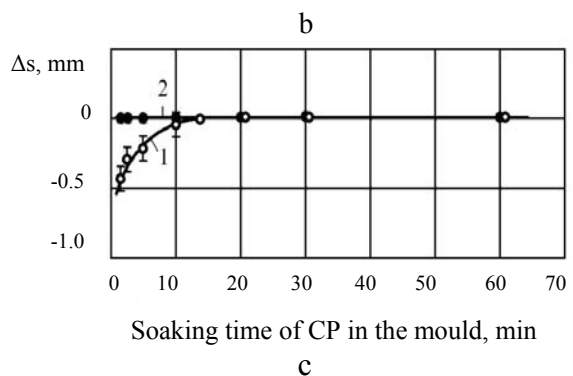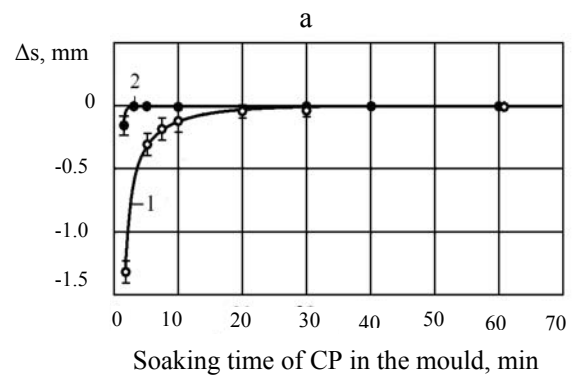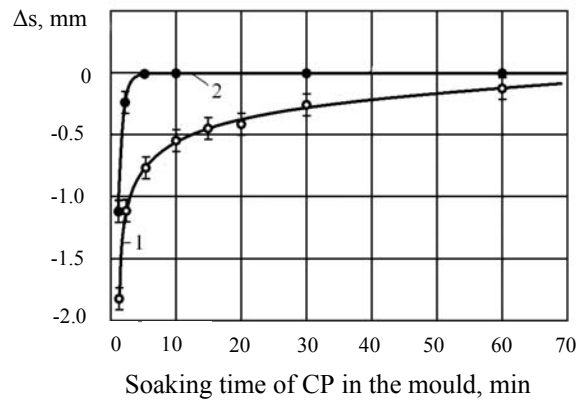
Figure 4. Interrelation of strain value of CP made of ceresin of grade 95 (a), paraffin (b), glycerine-rosin ether (c), alloy No.7 (d) and its soaking time in the mould: 1 – conditionally free shrinkage; 2 – absolutely hindered shrinkage

mould during its forming, we will consider the functions illustrated in Figure 4. Figure 4 shows the value of CP strain as a function of CP cooling time

in the mould under conditionally free and absolutely hindered shrinkage. The analysis of functions presented in Figure 4 shows that even a relatively short period of CP cooling in the mould under completely hindered shrinkage prevents its strain. Apparently, under conditions of absolute hindered shrinkage solidification of CP material provides the same amount of plastic deformation in all (thick and thin) elements of CP and cause equality between coefficients of thermal linear expansion (CTLE) and coefficients of linear shrinkage of CP material of its thick and thin elements. Therefore, residual stresses in the body of CP do not occur and, accordingly, do not result in its strain.

The functions in Figure 4 show that non-simultaneous solidification and temperature differential in solidified and cooled elements of CP do not cause its strain starting from the moment of plastic-elastic transformation of CP material under conditions of absolutely hindered shrinkage. Since the solidification and initial period of CP cooling under conditions of absolutely hindered shrinkage prevent its strain, it is possible to conclude that preconditions of CP strain do start at these stages. Hence, the main factors of CP distortion are differences in areas of plastic deformations in thick and thin elements of CP, and also temperature of plastic-elastic transformation of CP material.
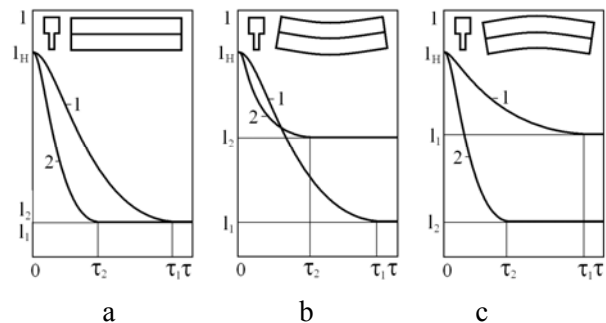
The functions of alteration in length of thick and thin element of CP of beam-type and T-section through time are presented in Figure 4. The schemes of CP strain by the moment of CP cooling to room temperature are given.

The scheme shown in Figure 5a corresponds to alteration in length of thick and thin element of CP through time under equality of shrinkage values of these elements material. The present case can be applied to above-described case related to solidification of CP made of ceresin, paraffin, or glycerine-rosin ether and alloy No.7 when there is no strain.

The implementation of this scheme corresponds to the situation when CTLE values of material are equal between each other in thick and thin element of CP, i.e. when the value of implemented plastic deformation of both elements of CP being formed was identical.

The scheme presented in Figure 5b corresponds to alteration in length of thick and thin element of CP through time when the value of material shrinkage in thick element (α_T) is more than coefficient of material shrinkage in thin element (α_T). This situation corresponds to

solidification scheme of CP under free and conditionally free shrinkage (see Figure 3, except for CP made of ceresin and paraffin) and causes their strain (hollow type of CP).

a   b   c

Figure 5. Alteration in length of thick (1) and thin (2) element of CP of beam-type and T-section during CP cooling, the schemes of CP strain

The scheme illustrated in Figure 5c corresponds to alteration in length of thick and thin element of CP considered through time when $\alpha_T < \alpha_T$. This case corresponds to schemes of CP solidification which lead to shrinkage reduction of pattern material in thick element and, as result, to hollow type of CP.

The formation of strain in accordance with the scheme presented in Figure 5c is typical for a number of pattern materials containing polymeric material (materials). Apparently, solidification and cooling of these pattern materials under conditions of shrinkage stopping causes formation of greater coefficient of material shrinkage in thin element of CP in comparison with the coefficient of linear shrinkage of the material in thick element of CP. This phenomenon is related to site character of polymer macromolecules arrangement under effect of stresses occurring in CP material. So, the peculiarities of macromolecule structure of polymeric materials and definite properties of a solvent material surrounding these macromolecules are the reason for not only changes in the linear shrinkage coefficients of CP elements but also for site (structural) residual stresses formation.

From a course on polymeric materials it is known that amorphous polymers are characterized by glass transition temperature (t_g) below which the molecules can not be reorganized in arrangement under application of stresses (glass transition temperature of polyethylene is $t_g = -120$ °C, polypropylene is $t_g = -15$ °C). Meanwhile, the

linear molecules of amorphous polymers are the most stable in coagulated conformations (coils), i.e. when there are no stresses in CP material.

When there are tensile stresses in CP material being solidified, the solidification temperature of which is considerably higher than glass transition temperature of polymers used, the polymer macromolecules present in CP material are straightened and oriented along the direction of force applied to CP. Since a degree of polymer macromolecules straightening (orientation) depends upon stress value, then the degree of polymer macromolecules orientation in thin element of CP will be higher than in thick one. Correspondingly, the value of linear shrinkage of CP material in its thick element will be less than in thin one that corresponds to conditions of the scheme presented in Figure 5c.

The presence of polymeric material in any pattern material does not always cause convexity in CP cooled down to room temperature which is demonstrated in functions presented in Figure 6.

Function 1 in Figure 6a corresponds to condition $\alpha_T > \alpha_\tau$. Function 2 in Figure 6a till the 2-nd minute of CP cooling in the mould corresponds to condition $\alpha_T > \alpha_\tau$, after the 2-nd minute of cooling in the mould function 2 in Figure 6a corresponds to condition $\alpha_T < \alpha_\tau$. Function 1 in Figure 6b till the 20-th minute of CP cooling in the mould corresponds to condition $\alpha_T > \alpha_\tau$, after the 20-th minute – to condition $\alpha_T = \alpha_\tau$. Function 2 in Figure 6b till the 2-nd minute CP cooling in the mould corresponds to condition $\alpha_T > \alpha_\tau$, after the 2-nd minute of CP cooling - to condition $\alpha_T < \alpha_\tau$. Function 1 in Figure 6c corresponds to condition $\alpha_T > \alpha_\tau$. Function 2 in Figure 6c corresponds to condition $\alpha_T = \alpha_\tau$. Functions 1 and 2 in Figure 6d correspond to condition $\alpha_T > \alpha_\tau$ irrespective of conditions of CP solidification and cooling.

So, except for polymer presence in the pattern material, the second necessary condition of convexity origination in CP is properties of its material-basis and conditions of solidification and cooling in the mould.

The analysis of data obtained shows that for prevention or reduction of strain, any of three approaches should be applied: 1) to cool CP in the mould (die mould) until all the parts of CP reach the air temperature in a forming area of casting shop; 2) to provide conditions of absolutely hindered shrinkage for all the elements of CP without exception, up to their cooling to air

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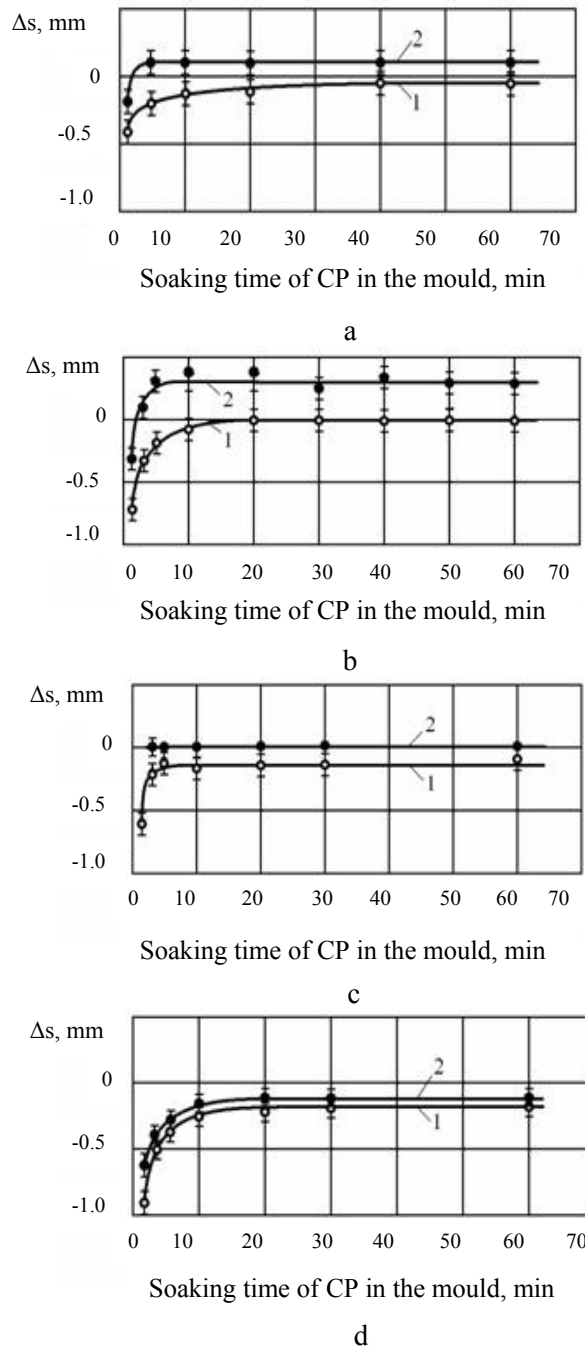
Figure 6. Interrelation of strain value of CP made of alloy No. 3 (a), alloy No. 4 (b), alloy No. 5 (c), alloy No. 6 (d) and its soaking time in the mould: 1 – conditionally free shrinkage; 2 – absolutely hindered shrinkage

temperature in the forming area of casting shop; 3) to use unshrinkable pattern mixture for CP making.

Cooling in the mould (die mould) to room temperature in the forming area of casting shop is

related to decrease of parameter of turnover of the mould (die-mould) used. With the purpose of turnover increase, the mould (die mould) with CP in it should be subjected to forced cooling, for example, in flowing water.

Solidification and cooling of pattern to room temperature in the mould (die mould) under conditions of absolutely hindered shrinkage for a range of pattern mixtures cannot be implemented because of CP cracking. Therefore, for CP making under conditions of absolutely hindered shrinkage it is necessary to use pattern mixture with a high crack resistance. In particular, as our research has proved, polyethylene wax of grade PV-200, brown-coal wax of grade Romonta Y-S80, Romonta Y-S2, Romonta N, Alexandrine brown-coal wax (Alexandria, Ukraine), oil ceresin of grade 80, synthetic ceresin of grades 100, alloy No.1 and alloy No.2, pattern mixture grade VIAM-102, V-1, R-3, MVS-3A, MVS-15 turned out to be completely unsuitable as the materials for CP making under conditions of their cooling to room temperature and absolutely hindered shrinkage.

Conclusions

1. The non-uniformity of plastic deformation of material in CP elements causes strain of CP solidified in non-rigid mould.

2. Non-simultaneous solidification and differential temperatures in elements of CP being solidified and cooled do not cause its strain starting from the moment of plastic-elastic transition of CP material under conditions of absolutely hindered shrinkage.

3. Strain in the form of deflection of CP solidified under conditions of absolutely hindered shrinkage is determined by orientation (structural) stresses in its material.

4. In order to decrease strain value, two approaches should be considered. The first one - to cool CP in the mould (die mould) until all the parts of CP reach room temperature (air temperature in the forming area of casting shop). The second approach means that for CP making it is recommended to use material having either zero or close to zero linear shrinkage.

References

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О короблении литых моделей отливок в литье по выплавляемым моделям

Репях С.И.

Установлены причины коробления литых выплавляемых моделей отливок в литье по выплавляемым моделям. Приведены рекомендации по повышению точности формы выплавляемых моделей.