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QUALITY ASSURANCE OF CYLINDRICAL CASTED PARTS WITH SMALL THICKNESS

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ABSTRACT

The casting of the cylindrical parts with great diameter and small thickness and intermediary flange is difficult because of the great values of the forced contraction. Thus the value of the tensile stress is very great and can determine the fracture of the part in zone of the thermal knot. For assurance of the quality of these parts some technological solutions are necessary. The paper shows the analysis of this aspect and presents practical solutions.

KEYWORDS: casting, solidification, small thickness, flange

1. Introduction

The casting is a very good technological method for obtaining complex engineering parts.

The parts with great diameter and length and very small thickness when have intermediate flange present a thermal knot (Fig.1).

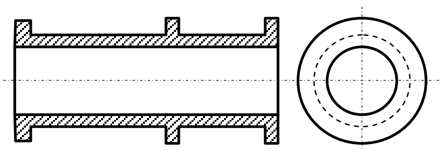

Fig. 1. *Example of a part with thermal knot.*

The thermal knot has a great influence on the solidification process and on the quality of the casted part. This can determine a contraction hole (shrink hole) in the case of the metallic material with great contraction coefficient at the solidification.

In the case of the metallic material with fragility (in the casted state) and great thermal contraction coefficient, cracks can be developed.

Under the practical condition, cracks appear with a relatively great frequency.

In this paper we develop the study in the aim of analyzing the casting and solidification processes for eliminating the causes that can determine the appearance of cracks in zones of the thermal knot.

2. Analysis of the solidification process

We will consider that the solidification process begins immediately, in the certain point, when the casting process is finished. We admit that the material of the cast form (mould) is homogeneous and uniform. Under these conditions, the heat flux from the casted material to the casting mould, at the beginning of the solidification process, is constant.

In the following stage the thermal flux is different in the different geometrical points of the thermal knot.

Admitting a macro-element with the volume V and surface area A, we get of the equation of heat flux [1]:

$$\bar{\alpha} A\left[T(t)-T_0\right]=V\dot{Q}_{gen}-V\rho c\frac{dT}{dt} \quad (1)$$

Where:

$$\dot{Q}_{gen}=\rho_s \Delta H_f \frac{\partial f_s}{\partial t} \quad (2)$$

The function f_s has the form:

$$f_s = a + bT$$

and, after the integration, using the initial condition, we obtain the time t_s of solidification of the parts defined by equation:

$$t_s=-\frac{\rho c V}{\alpha A}\left(1-\frac{b}{c}\Delta H_f\right)\ln\left(\frac{T_f-T_0}{T_i-T_0}\right) \quad (3)$$

In the above equations we have:

$\overline{\alpha}$ -mean heat transfer coefficient, ρ-density, c-specific heat, ΔH_f- latent heat of melting, T_f-melting temperature, T_i-casting temperature, T_0- temperature of the mould.

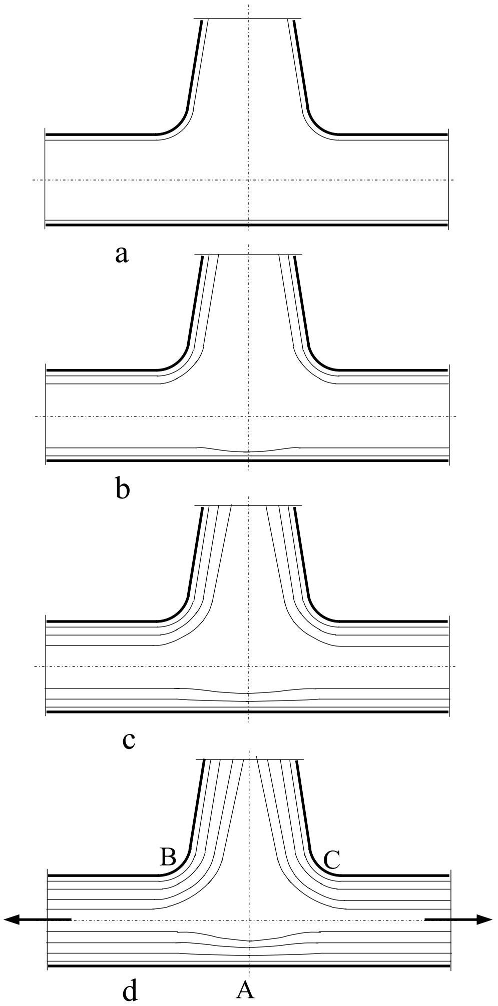

***Fig. 2.** Evolution of the solidification front.*

The equation (3) proves that the solidification time is greater when the local volume is greater. Therefore the greatest solidification time is in the centre of the thermal knot.

The solidification front, in the thermal knot, at various moments of the solidification process is represented in Figure 2.

In the first phase of the solidification process, the intensity of the heat transfer is constant and, consequently, the solidification front is uniform in the entire contour of the form walls (Fig. 2a).

In the following phase (Fig. 2b), the intensity of the heat transfer decreases in the points B and C because of the peak form of the mould. Consequently the thickness of the solid layer in these points is smaller than in the points of the uniform thickness of the part.

In the point A, because of the great quantity of the melt metallic material, the thickness of the solid layer is small, too.

When solidification finishes, without the thermal knot, the two solidification fronts meet in the middle of the part wall.

In the thermal knot rests an important quantity of liquid metallic material. The thickness of the solid phase is variable with minimum value at the point A.

Simultaneous with the solidification process, the thermal contraction of the solid phase is developed, because the cast part has flanged at the both its heads. The part has a great length and, consequently, the absolute value of the free contraction is great.

Because we have forced contraction, the tensile stress in zone A can be greater than the strength of the material, in the given conditions, and the crack appears.

In the practical conditions, we found the cracks at the interior surface of the cast parts at the label of the point A.

3. The solution of the problem

The solving of the objective, the elimination of the cracking rescue, entails the control of the solidification process by the control of the heat transfer in the junction of the walls.

We consider the solidification module defined by the expression:

$$M = \frac{V}{S} \tag{4}$$

In this relation, V is the volume of the melting material and S is the surface of the heat transfer.

The solidification time is correlated with the solidification coefficient through the relation:

$$t = k \cdot M^2 \tag{5}$$

Definitely, in the above relations it is supposed that the intensity of the heat transfer is constant on the interface cast material-mould. In the real conditions, the heat transfer intensity has dynamic character and the evaluation of the correct value of the local intensity of the heat transfer is necessary.

For ensuring the control of the solidification time, respectively a correct value of the solidification module in the thermal knot, it is chosen one of the following methods:

- changes in the local form and thickness of the cast part,
- use of cooling elements,
- use of thermo-insulating sleeves included in the mould walls,
- modification of some mould walls by the forced heating or cooling.

Through the use of cooling elements in the construction of the casting mould, the real partial solidification modules change. For the calculus of the real solidification modules, in this case, the knowledge of the cooling coefficient k_i for the surfaces with the cooling elements or thermo-insulating sleeves is necessary. In this aim is used the equation that describes the heat quantity extracted by the mould from the cast part through unity of contact surface mould-cast part, in function of temperature gradient liquid alloy – mould and time, used by Chvorinov, at the definition of the exterior geometric solidification module, for the multiplication of real solidification module with the factor n in the conditions of the given thermo-physical characteristics of the available materials.

In Table 1 the thermo-physical characteristics of the various materials are showed. They are materials with small and great values of thermo-physical characteristics.

Table 1. *Thermo-physical characteristic of some materials*

Material	**Density** kg/m^3	**Specific heat** J/(kg K)	**Thermal conductivity coefficient** W/(m K)	**Heat accumulating coefficient** Ws/m K
Mould mixture (95% quartz sand + 5% sodium silicate)	1700	1312	1.5	1856
Mould mixture (97.8% quartz sand + 1.8% furfurol + 1% ortophosphoric acid)	1700	1356	1.35	1761
55.6% quartz powder + 22.8% quartz sand + 16.6% ethyl–silicate and catalyser	1600	1232	1.12	1579
46% zircon powder + 39% zircon sand + 16.6% ethyl–silicate and catalyser	2700	968	1.35	1881
Raw mould mixture (quartz sand and bentonite)	1800	1050	0.29	740
Dried mould mixture (quartz sand and bentonite)	1700	840	0.17	492
Low carbon steel	7850	840	50"	18157
Medium carbon steel	7850	800	46	16996
Cast iron	7200	540	40	12470
Siluminum (86-89% Al + 14-11% Si)	2600	880	160	19133
Bronze (90% Cu + 10% Sn)	8760	360	42	11508
Copper	8900	440	380	38575
Diatomite (brick)	550	840	0.17	280
Vermiculite	300	830	0.14	186

It is observed that the metallic materials, used as cooling elements, have the heat accumulating coefficient 10-30 times greater then of the mould mixture, and thermo-insulating materials have the heat accumulating coefficient 2-10 times smaller of than the mould mixture.

The exterior cooling elements for the casting of steel parts are worked frequently from steel (sheet or rod), in case of the complex form they are cast form cast iron, and in very complex form, the cooling elements form magnesite mixture are used.

The forms of the metallic cooling elements are showed in Figure 3.

Solving the problem is possible through the use of exterior or interior cooling metallic elements.

The interior cooling element can be used, but is important to establish very exactly its volume for ensuring complete melting. Otherwise the part may be rejected.

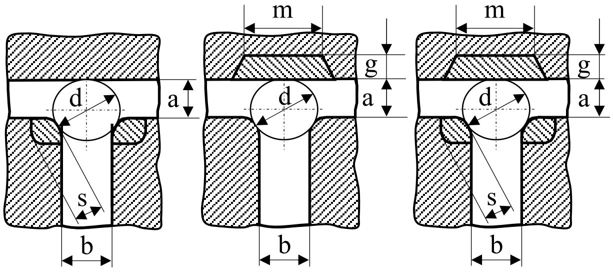

Fig. 3. *Forms of the exterior cooling elements.*

***Table 2**. Dimensions of the cooling elements*

Cooling mod	**Dimensions of the cooling space**, mm		**Dimensions of the cooling elements**, mm		
	a	*b*	g	s	*m*
Thermal knot cooled with two elements	from 20	to 20	-	0.5-0.6 *d*	-
	from 20	from 20		0.3-0.4 *d*	
	to 20	to 20		0.5-0.6 *d*	
	to 20	from 20		0.3-0.4 *d*	
Thermal knot cooled with one element	from 20 to 20 to 20	to 20	0.5-0.6 *a*	-	2.5-3 *b*
		from 20	0.5-0.6 *a*		2-2.5 *b*
		to 20	0.6-0.8 *a*		2.5-3 *b*
		from 20	0.6-0.8 *a*		2-2.5 *b*
Thermal knot cooled with three elements	from 2	to 20	0.4-0.5 *a*	0.4-0.5 *d*	2.5-3 *b*
	from 20	from 20	0.4-0.5 *a*	0.3-0.4 *d*	2-2.5 *b*
	to 20	to 20	0.5-0.6 *a*	0.4-0.5 *d*	2.5-3 *b*
	to 20	from 20	0.5-0.6 *a*	0.3-0.4 *d*	2-2.5 *b*

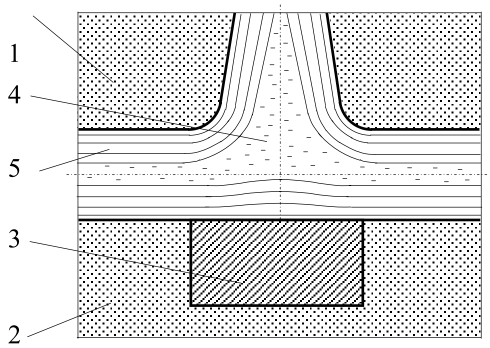

***Fig. 4.** Solidification with cooling element: 1-casting mould, 2-mould kernel, 3-cooling element, 4-liquid phase, 5-solid phase.*

The exterior cooling element, included in the mould kernel (Fig. 4), is the favorable method for intensifying of thermal flux in zone of the metal agglomeration.

The heat transfer between the cast metal and the mould is intensified, in the metal agglomeration zone, because the heat conduction coefficient increases.

Here it makes heat transfer through thermal conduction metal-metal more intense of thermal conduction metal-casting mould mixture. Consequently, the evolution of the solidification front is reversed in comparison with the before case mentioned.

As a result, the thickness of the solid phase in the point *A* is greater than the one in zones of the uniform thickness of the part walls. The dimensions of the cooling element are established in function of the dimensions of the part wall and intermediary rib.

Thus, for *a* equal of 25mm and *b* equal to 30mm, we must use a cooling element with dimensions: m=60-75mm and g=12.5-15mm.

4. Conclusions

The casting process of the parts with great diameter and length and small thickness, relatively, two marginal flanges and one intermediary flange is difficult because of three reasons:

- firstly it occurs a great thermal contraction after the solidification of the part,
- secondly the great fragility of the steel in the cast state,
- thirdly small value of the solidified crust.

As a result, these can appear a crack in the plan of the intermediate flange, in the thermal knot of the cast part.

This rescue may be diminished or eliminated by using exterior metallic cooling elements assembled in the kernel of the mould.

The dimensions of the cooling element are calculated in function of the characteristic dimensions of the part in zones of the thermal knot.

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