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MATERIALS ON DIES FOR PRESSURE DIE CASTING

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In the contribution the stress of die materials of thermal fatigue is defined and material life is derived theoretically and compared with the measured values. The important properties of the die materials as thermal conductivity, coefficient of thermal expansivity, modulus of elasticity and mechanical properties are described. Binding to it single die materials as carbon steels and chrome-tungsten steels are analyzed. As the perspective die material for pressure die casting of ferrous metals appears molybdenum with regard to advantageous properties.

Key words: stress of material, thermal fatigue, service life, material properties

Materijal matrica za tlačno lijevanje. U članku je definirano naprezanje materijala pri toplinskom umoru i izveden teorijski životno (radno) vrijeme materijala te uspoređene sa izmjerenim vrijednostima. Opisana su važna svojstva materijala, kao što je toplinska vodljivost, koeficijent toplinske rastegljivosti, modul elastičnosti i mehanička svojstva. U nastavku su analizirani materijali kao što su ugljični čelici te krom-volframovi čelici. Kao perspektivni materijal za tlačno lijevanje željeznih slitina se pojavljuje molibdan sa prestižnim svojstvima.

Ključne riječi: naprezanje materijala, toplinski umor, radni vijek, svojstva materijala

INTRODUCTION

At operation of pressure die casting dies are cyclically stressed on thermal fatigue. After exhausting of material sliding properties the end of die service life comes. For the more profound explanation it is necessary further to analyze thermal conditions and single important properties of die material during the operation of pressure die casting.

STRESS OF DIE AT PRESSURE DIE CASTING

At entrance of liquid metal with high temperature into die a heat comes from the

metal into the die surface according to Figure 1.

The layer of die face can be considered as a whole. If this layer is free and we know its linear coefficient of thermal expansivity α then at its temperature T_1 and its temperature before entrance of liquid metal T_0 the extension of the layer is [1,2].

$$\delta = a(T_1 - T_0) \qquad (1)$$

Because the layer cannot be expanded the compressive stress σ arises in it

$$\sigma = \frac{\delta m E}{m-1} \qquad (2)$$

where m – Poisson's constant, E – Young's modulus of die material. If we substitute competent values E = $2{,}2\cdot10^5$ MPa, α = $1{,}3\cdot10^{-5}$, m = 3,3, T_o = 300 °C, T_1 = 600 °C we obtain σ = 1 200 MPa that evokes a tensile stress

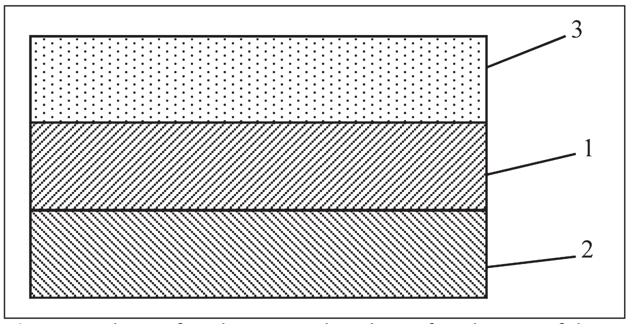

Figure 1 The surface layer 1 and undersurface layer 2 of the die at filling the die with the liquid metal 3

in the layer under the surface layer. However after drawing the casting from the die the surface layer cools and a tensile stress arises in it.

By repeating this process as a thermal fatigue at the tensile stress it is arising a danger of cracks. After ten till hundred thousand cycles the cracks arise really and the life of the die material ends.

THE SERVICE LIFE OF DIE MATERIAL

If the number of the pressing liquid metal into the die N is considered as the quasicontinous function with indirect proportional dependence on the pouring temperature T then every elementary increase of the pouring temperature dT means lowering indirect proportional cycles of the die material service life $-\frac{dN}{N}$.

Then it is:

$$dT = -k\frac{dN}{N} \qquad (3)$$

where: k – constant /°C.

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Table 1 **Important properties of die materials**

Material	Addition / %	Modulus of elasticity / MPa	Coefficient of thermal expansion / m^{0}C^{-1}	Thermal conductivity / kJm^{-1}s$^{-1 0}$C^{-1}	Hardness / HBS	Resistance against melting
Copper	-	105 000	16,5	0,393	60	excellent
Beryllium bronze	0,5 Be	110 000	16,5	0,0836	400	excellent
Heat treat soft steal	0,4 C	220 000	11,7	0,0627	8	excellent
Low alloy heat treat steel	0,3 C, 1 Cr	215 000	10,5 - 13	0,0418	300 – 400	good
High alloy heat treat steel	0,3 C, Cr, W, Mo, V	210 000	10,5 - 13	0,0188 – 0,0334	350 – 500	good
Austenite steel	0,1 C,18 Cr	200 000	19,5	0,0209	130	very bad
Molybdenum	-	350 000	4,9	0,146	170	excellent
Molybdenum - titanium	-	350 000	3,2	0,125	200	excellent

After integration from T1 up to T and from N1 up to N we obtain:

$$T - T_1 = -k \ln N + k \ln N_1 \qquad (3,1)$$

We adapt it and we change on decadical logarithm [3,4]:

$$\log N = A - k_1 t \qquad (3,2)$$

where: A – constant, $k_1 = \frac{2,3}{k}$ /°C^{-1}.

The relation (3.2) corresponds to the measured results according to Figure 2 where the logarithm of cycles N is dependent on the pouring temperature T at pouring single alloys of zinc, aluminum, copper and ferrous alloys (cast iron, steel).

It is possible to reach the increase of die service life by single or total use of following measures [5,6]: the use of die material with the smallest thermal expansion, the smallest modulus of elasticity and the largest conductivity.

Ceramic materials accommodate to the first claim but they do not accommodate to the second claim and as very brittle ones they did not prove at tests.

Molybdenum that is shown as a perspective die material accommodates partly to the third claim. It is however expensive at lower temperatures it has area of brittleness and at higher temperatures with regard on its sublimation it is necessary to secure a surface protection. For increase of die service life at pressure die casting brass it is possible to use the alloys Inconel 617 and Haynes together with higher temperature of die.

PROPERTIES OF DIE MATERIALS

Die materials must fulfil properties going out of from stress of dies in operation. They are mainly thermal expansion and modulus of elasticity, mechanical properties, resistance to thermal fatigue [6] and chemical stress of die.

Thermal expansion and modulus of elasticity

At smaller thermal expansion and modulus of elasticity stress at certain thermal impact at die operation is also smaller. It dependences on modulus of elasticity of elementary metal that is only little changed by alloying addition. Modulus of elasticity and thermal expansion coefficient of die materials are on Table 1 [7,8].

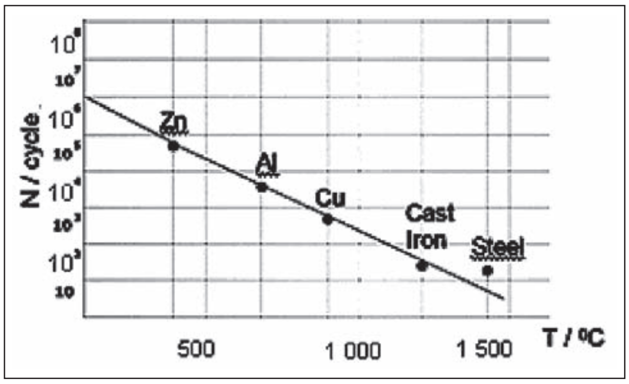

Figure 2 Dependence of die material service life at pressure die casting on pouring temperature

Thermal conductivity

It is an important property. It shows also at running property of metal. In [9] length of flow is compared in dependence of the die material alloy Cu-Be and steel that is 44 percent shorter that at steel.

Mechanical properties

It is possible to change mechanical properties by alloying and heat treatment so that deformations are in elastic area. It is however possible only at casting of zinc alloys at temperatures low. The yield point is lowered at high temperatures and plastic deformations occur. It manifests that it is necessary to temper die steels on lower strength. Plastic deformations are tired out slower.

Chemical stress of die materials

At chemical stress of die material in the first row there are alloys dissolving iron especially aluminum alloys. It is possible to find out it from equilibrium diagram of iron and elementary metal of alloy then Fe-Zn, Fe-Al, and Fe-Cu. The higher is temperature of alloy the higher is danger of chemical dissolving die. At brass zinc penetrates into die cracks. Also at aluminum alloys it can come to very expressive effect. According to equilibrium diagram Fe-Al at 700 °C aluminum creates the brittle intermetallic phases $FeAl_2$, Fe_2Al_3 and $FeAl_3$ [10,11]. At slight thickness they can influence unfavorably surfaces of casting and die and they can demolish the die. This appearance is well-known as a sticking. Especially improperly situated cores and parts of die exposed to flowing alloy at filling die cavity are endangered. We face to attacking by the large hardness of die face and protective layers.

MATERIAL FOR DIES

For dies of pressure die casting carbon steels, low-alloyed steels, high-alloyed steels, chrome steels, tungsten steels and chrome-molybdenum steels are used.

- Carbon steels are used for die parts being not in contact with liquid metal as the clamping die box, the guide and supporting plate of ejectors and the hydraulic drawer of cores.
- Low-alloyed steels are used especially for zinc alloys. They are steels with the content 0,30 up to 0,45 % C alloyed with Cr respectively V and Mo. Further they are carbon constructional steels with high strength after heat treatment 1 000 up to 1 200 MPa. It is possible to reach martensitic structure into larger depth with carbide-created elements. At tempering they shift the decrease of martensit decomposition on pearlit into higher temperatures. It limits their use on lower temperatures of pour when the decrease of hardness is not large.
- High-alloyed steels contain so many carbide-created elements that by tempering at temperature higher than 400 °C it comes to increase of hardness measured at room temperature marked as the secondary hardness. It is higher at larger number of the carbide-created elements connecting with the origin of complex carbides and shifting into higher temperatures. Therefore the steels for dies shifted from the chrome and tungsten steels to the combinations W-Cr, W-Cr-Co, Cr-Mo, Cr-Mo-V, Cr-Mo-V-W. At hardening under temperature of the martensite creation beginning the steel contains the martensite and the residual austenite that at tempering decomposes on the martensite or bainite and with it possible to contribute to the secondary hardness [12].
- Chrome steels are martensitic with so large content of chrome that they are anticorrosive and heat-resisting and with so large content of carbon that they are hardenable. By additions of the carbide-created elements the finer grain at higher temperature of austenitization and shifting zone of secondary hardness into higher temperatures is reached.
- Tungsten steels are the steels with the content 0,30 up to 0,35 % C, 2 up to 2,5 % Cr and 4,5 up to 11 % W. In USA they are without further additions in Slovakia still with addition V and Ni and in Germany also Co. The tungsten-chrome steels have larger hardness into higher temperatures of tempering. They match on dies for resistance to wear and sticking e.g. in region of gate [13,14]. The thermal conductivity of the tungsten steels is not so good as at the steels without tungsten. Tungsten and cobalt improve however the resistance to wear [15].
- Chrome-molybdenum steels have the content approx. 0,30 % C, 2,8 up to 5 % Cr, 0,5 up to 2,5 % Mo most often also the addition of V sometimes also W and Co. the cobalt lowers the inclination to brittle fracture at higher temperatures and increases plastic properties in heat. With lowering content of chrome and further additions it was reached the considerable improvement of service life. The tests at die casting brass showed that the better resistance to cracks is at tempering on smaller strength 1 050 up to 1 300 MPa than on 1 600 MPa. At die casting aluminum alloys it would be necessary the increase effect of protective layers obtained by nitriding or sulfonitriding recommended at these steels [16,17].

MATERIALS ON DIES DEVELOPMENT DIRECTIONS

The important factor is the steel quality not only according to composition but also according to cleanliness. It goes about low content of sulfur and phosphorus but also the smallest content of inclusions their fineness and regular distribution. The inclusions always lower resistance to origin of cracks network. Remelting steel in vacuum is also important. It is possible to obtain the improvement of material service life by further change of the chrome, molybdenum, tungsten and vanad so that the suitable secondary hardness is reached at the smallest content of these elements. We obtain with it also simultaneously the largest possible thermal conductivity. It is possible to reach the further improvement by lowering hardness after tempering. [18,19]

At large series of die casting in production of automobiles the choice of materials on dies for zinc alloys aims at chrome-molybdenum steels used for die casting aluminum alloys. The analogous tending can be occurred for other alloy die cast.

Molybdenum is appeared as the perspective material on dies for die cast. It has the relative high thermal conductivity the low coefficient of thermal expansivity so that also at large modulus of elasticity the high stress does not rise. It is brittle in the interval of low temperatures. It can come to cracking. As to it has not the protective layer on the die face e.g. nitriding one it comes to sublimation at die cast. [20]

Further the composite materials have a perspective. According to [21,22] the filling chamber was from the composite materials reinforced by particles of titan (TiB and TiC) for die cast of aluminium alloys in USA.

CONCLUSION

In the contribution the cyclical stresses on thermal fatigue of die materials are described and analytically derived. Further exhausting of the material sliding properties are derived with the end of die service life. The single properties of the die materials are also described. The development was very important at transition from zinc to aluminum and copper alloys at die cast and it can do service at transition from research to working of the ferrous alloys die cast.

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