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# STRUCTURAL INFLUENCE AND CONDITION OF DIE CAST STEELS ON DIES WORKING CAPACITY

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**Abstract-** The acceleration of scientific- technological progress is closely associated with the development of materials technology as science and technology for obtaining materials and products based on them, ensuring the reliability and high performance of mechanisms, machines, devices and other equipment. The variety of materials used in the units of machines and mechanisms makes it possible to provide the flexibility in the production of both the materials themselves and parts from them in the absence of any component or equipment necessary for the synthesis of a particular brand. Meanwhile, the availability of a wide range of materials also allows for choosing material depending on its purpose and the requirements of a particular unit. The influence of alloying elements on the structure and structural condition of die steels on the working capacity of heavily loaded cold-working dies has been considered in the paper. It has been established that with an increase in carbide inhomogeneity in steels, the bending strength and impact elasticity decrease.

**Keywords:** Quenching, Strength, Impact Elasticity, Carbide Phase, Inhomogeneity, Deformation.

## 1. INTRODUCTION

The annual increase in the volume of production of parts obtained by cold deformation method, including sheets and magnetic cores of electric motors from difficult-to-deform structural materials of high strength, toughness and wear capacity, causes the creation of special steels for cutting and guiding parts of punching dies with high performance properties. The effective solution of these problems largely determines the productivity of labor during stamping, the possibility of cost-effective mechanization and automation of stamping production. So far, the cutting parts of punching dies are mainly made of semi-heat-resistant steels of the ledeburite class containing 6-12% of chromium.

In all cold forming manufactures, dies with steel cutting parts are mainly used. In these steels, the number of carbides (by volume) depends on the carbon content and is 13-14% for Kh12F1 steel, 15-16% for Kh12M steel and 19-20% for Kh12 steel [3,8]. A high chromium content in them, combined with a high carbon content, always promotes the formation of coarse carbides, and also hinders the diffusion of carbon, reduces its solubility in austenite, and thereby increases the carbide inhomogeneity of the steel. The grain size of carbides and their distribution in the steel structure are often determined by the conditions of crystallization and the degree of deformation during hot machining.

## 2. MAIN PART

The working capacity of dies is significantly influenced by the structure and structural condition of die steel ingots. At that, the emphasis is on the position of the carbide inhomogeneity of the die steel, depending on the weight of the ingot and the diameter of the rolled products [9, 10]. The chemical composition of semi-heat-resistant steels with high hardness for heavily loaded cold-working dies is presented in Table 1.

Table 1. The chemical composition of semi-heat-resistant steels with high hardness (%)

| Steel grades | C | Si | Cr | W | Mo | V |
|---|---|---|---|---|---|---|
| KH12 | 2.0-2.2 | 0.15-0.35 | 11.5-13.0 | - | - | - |
| KH12M | 1.45-1.65 | 0.15-0.35 | 11.0-12.5 | - | 0.4-0.6 | 0.15-0.30 |
| KH12F1 | 1.25-1.45 | 0.15-0.35 | 11.0-12.5 | - | - | 0.70-0.90 |
| KH12VM | 2.0-2.2 | 0.20-0.40 | 11.0-12.5 | 0.5-0.8 | 0.6-0.9 | 0.15-0.30 |
| KH6VF | 1.05-1.15 | 0.15-0.35 | 5.5-6.5 | 1.1-1.5 | - | 0.50-0.80 |
| KH6HFT | 0.80-0.90 | 0.15-0.35 | 5.0-6.0 | 0.9-1.3Ni | 0.05-0.15Ti | 0.30-0.50 |
| KH6F4M (DI770) | 1.65-1.75 | 0.20-0.50 | 5.7-6.5 | - | 0.5-0.8 | 3.70-4.20 |
| KH12F4M (DI51) | 2.0-2.2 | 0.20-0.40 | 12.0-13.5 | - | 0.5-0.8 | 3.40-4.00 |

As can be seen from Table 2, with an increase in the degree of forging the carbide inhomogeneity severity on the surface and in the center of rolled products decreases sharply, and in rolled products with a diameter of 30 mm it completely disappears.

Therefore, samples made from rolled products of large diameters, after quenching, having high hardness (62-66 HRC) and wear resistance, often have insufficient strength and low impact elasticity. Their high wear resistance is caused by significant amount of excess carbide phase, represented mainly by $M_7C_3(M_{23}C_6)$ carbides and relatively high hardness (1050-1600HV) [4-10]. According to researches carried out by Y.A. Geller [1] and L.A. Poznyak [3], with an increase in carbide inhomogeneity in KH12M steel from 2 to 10 points, the bending strength, impact elasticity and coercive force (Nc) decrease within 3050-2000 MPa, 500-150 kJ/m$^2$ and 70-50 oersted, respectively.

Table 2. Carbide inhomogeneity of KH12M steel depending on the degree of forging

| Ingot weight, kg | Size of rolled products, mm | Degree of forging | Carbide inhomogeneity severity | | |
|---|---|---|---|---|---|
| | | | Edge | 1-2 radius | Centre |
| 750-300 | 130 | 4.4-2.3 | 4.0-5.0 | 4.5-6.5 | 8.0-9.0 |
| 750-300 | 90 | 9.0-4.9 | 4.0-5.0 | 4.0-6.5 | 5.0-7.0 |
| 750-300 | 60 | 20.0-11.0 | 2.0-3.0 | 2.0-3.5 | 4.0-5.0 |
| 750-300 | 30 | 82.0-43.8 | - | - | - |

High-chromium steels, due to the high stability of supercooled austenite, are calcined in sections up to 200-300 mm when cooled in oil and up to 70-80 mm when cooled in air. This allows for the using of steels with 6-12% chromium for large dies and cold-working molds, but at the same time, mechanical properties and deformation during heat treatment are highly dependent on the development of carbide inhomogeneity, which strengthens with an increase in the amount of chromium (≥3.0%) [2, 5, 11]. Carbide inhomogeneity during heat treatment causes a deformation anisotropy. This is due to the fact that the coefficient of thermal expansion of carbides is by 30% lower than that of the base metal [9-11]. Carbides embedded in the matrix act as wedges that prevent the metal expansion during heating and metal contraction during cooling. It is known that carbides expand more along the lines and shrink in the perpendicular direction (Figure 1).

In the paper [4, 9] the influence of the amount and conditions of distribution of carbides on the deformation of KH12, KH12M and KH6VF steels (Figure 2) was studied, it was found out that during forging without stirring the structure retaining significant carbide inhomogeneity, the anisotropy, deformation of KH12M steel became 2-3 times less and deformation of KH6VF steel became 4-5 times less than that of KH12 steel, Figure 2. Forging with threefold deflection and drawing made it possible to reduce the anisotropy of deformation of KH12 steel by 2-2.5 times, but at the same time it was 2 times greater than that of KH6VF steel. Steels of this type are considered the least deformable during phase transformations, since the availability of significant amount of residual austenite after quenching compensates for the increase in volume caused by the formation of martensite. Due to the large amount of chromium and carbon, the formed austenite is resistant to disintegration at almost any supercooling. This makes it possible to perform air quenching of even massive parts of dies, which is also an advantage of these steels and facilitates their heat treatment.

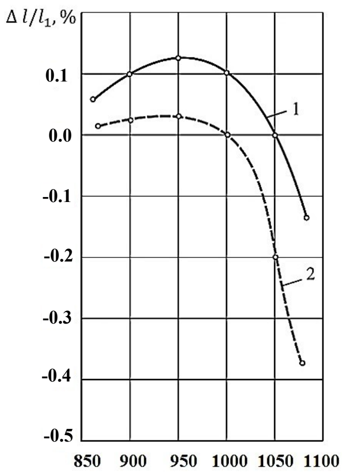
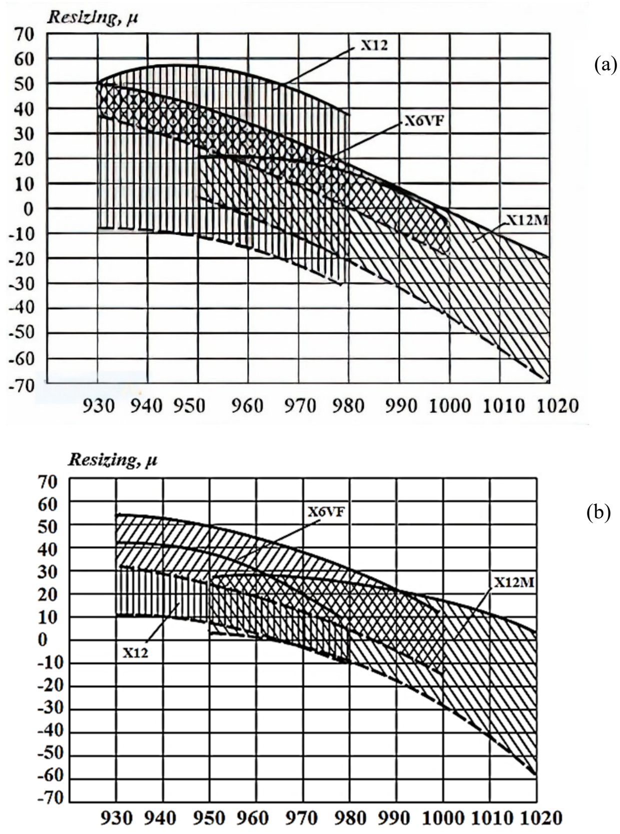



Figure 1. Change in the length of samples (from KH12M steel) depending on the direction of carbide lines and quenching temperature 1. longitudinal, 2. transverse direction




— along ---- across carbide lines

Figure 2. Change in sample diameter depending on temperature and forging conditions, (a) forging to size (drawing), (b) forging with threefold deflection and drawing

High wear resistance and low deformation during heat treatment, which these steels are able to provide, have led to their widest distribution as a material for working parts of punching dies. In recent years there was a tendency to reduce the carbide inhomogeneity and change the nature of the distribution by reducing the content of carbon, chromium and adding other strong carbide-forming elements [9].

It has been established that carbide inhomogeneity decreases most effectively with a decrease in the content of carbon and chromium, in addition, they contribute to a change in the type and composition of carbides. Strong carbide-forming elements: vanadium, titanium, niobium, etc., also are grinding and influence relatively well on the uniform distribution of carbides [9]. These elements create conditions for the significant saturation of austenite with alloying components, contribute to the development of dispersion hardening during tempering and obtaining heat resistance [4, 9]. Dispersion hardening is caused by the precipitation of fine special carbides of alloying elements from martensite; their sizes at the initial stage of the process are 40-50 NM. It is accompanied by the increase in hardness by 3-10 HRC. At that, the viscosity decreases. The degree of embrittlement depends on the conditions for the carbide's precipitation: along the boundaries and as per the grain volume. During electron microscopic investigations it was found out that in steels with molybdenum, after tempering along the grain boundaries, carbides are not precipitated. When developing steel for punching dies, this effect is more acceptable in order to reduce intergranular brittle fracture of working parts during operation. In addition, molybdenum worsens thermal conductivity to a lesser extent than other elements and positively influences on the hardenability and fatigue properties of steel.

Observations during operation show that the temperature in the cutting edge of tools made of steel with molybdenum is by 5-10 °C lower than that of those alloyed with tungsten and vanadium [1-4]. It is known [9, 11] that the carbon content increases up to 1.1% the strength of carbon steels after quenching and low tempering (62-64 HRC), determined during bending. The higher concentration of carbon in steel reduces the strength due to the noticeable negative effect of excess cementite. Thus, in order to obtain high strength, the amount of cementite-type carbide phase should not exceed 18-20% by volume. As studies have shown [11], the amount of the carbide phase is proportional to the carbon content in the steel, if the carbide type does not change during alloying. Therefore, the carbon concentration in alloy steel containing cementite should be set within 1.0-1.1%. Alloying of such steels with chromium and molybdenum increases the strength of hardened and low-tempered steel.

However, the positive effect of these elements becomes apparent when the content of chromium is up to 3-3.5% and molybdenum up to 0.4-0.5% and is caused by the transition of these alloying elements into martensite. In the case of the formation of limited solid solutions, the properties improve until the limiting concentration is reached. The higher content of chromium and molybdenum reduces the steel strength, which is caused by the change in the carbon content in the martensite of the hardened steel. Thus, the rational alloying of die high-strength steel, hardened to primary hardness, is associated with the limiting saturation of martensite with carbon and alloying elements. This is controlled by the appearance of a special carbide in the structure of the annealed steel, which makes it possible to reasonably select the required steel composition.

## 3. RESEARCH RESULTS AND THEIR DISCUSSION

The performed analysis showed that most cold forming dies are made from semi-heat-resistant steels alloyed mainly with chromium, vanadium and molybdenum. These steels are mainly produced by various methods of melting, followed by additional processing of cast section. The main reasons for the failure of heavily loaded dies of cold sheet stamping are premature wear, crumbling as well as flaking associated with insufficient resistance to brittle fracture of the material of cutting parts. In addition, the nature of the distribution and dispersion of excess carbides in them also have a great impact on the destruction and wear rate of cutting edges in heavily loaded punching dies. This is mainly due to the appearance of local stress peaks in coarse particles during loading, as their distribution deteriorates, the resistance of steels to fatigue damage decreases and leads to accelerated fracture.

In factories for cutting parts of dies, different forms of blanks are used, made from high-chromium die steels. Rings forged from large-section rolled products without additional reduction are often used as the primary blank for the sectors of dies and punches. However, the experience of recent years shows that one of the disadvantages of high-chromium steels is the increase in carbide inhomogeneity, which, as the diameter of the original rolled product increases, due to fatigue damage, sharply worsens the mechanical properties of cutting parts and reduces the durability of dies. The importance of the problem is explained by the fact that complex punching dies, depending on the dimensions of the part to be punched, are made from large rolled products. The carbide inhomogeneity, naturally, in this case is the largest and, as found out, significantly reduces the resistance to fatigue damage and has a negative effect on the overall durability of the dies. The study of cutting parts of stamps made at different factories showed that the carbide inhomogeneity severity fluctuates in very large intervals, from 3 to 7 points. Of the tested matrix sectors, 70-80% corresponded to 5-6 points of carbide inhomogeneity. Apparently, this to some extent predetermines also the low durability of punching dies manufactured at these enterprises.

The performed studies confirm that the main reasons for the premature destruction of the cutting parts of the dies are low physical and mechanical properties, as well as the presence of a pronounced carbide inhomogeneity. From the destroyed sectors of dies and punches, micro slices were selectively fabricated to study non-metallic inclusions and carbide structure. It is known that contamination with non-metallic inclusions and unevenly distributed excess carbides worsen the technological and operational properties of stamp materials. In all studied parts, the most common non-metallic inclusions are oxides, while inclusions in the form of sulfides and silicates are rarely observed. During the study of the carbide inhomogeneity of the destroyed parts it was found out that it does not always correspond to the standard scale, the abnormality of the structure is an increased severity of carbide phases and carbide networks, Figure 3. Accumulations of carbides in certain areas are often a stress concentrator and, under certain external forces, create the risk of fatigue cracks, Figure 4.

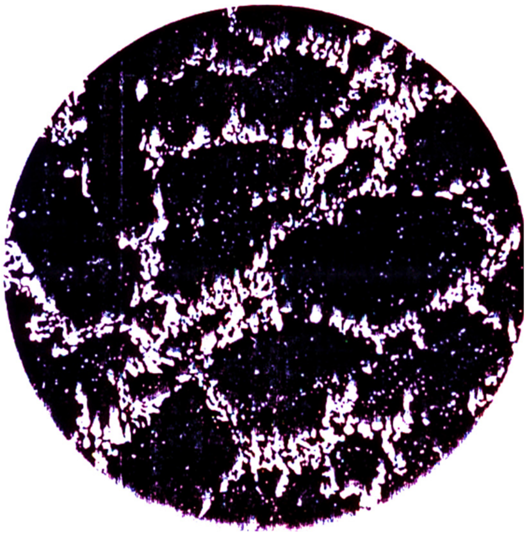


Figure 3. Slightly deformed networks of coarse eutectic carbides

Figure 4. Micro cracks formed due to fatigue

Therefore, the applied process of hot plastic deformation and heat treatment must ensure the fragmentation of large carbides and prevent the formation of carbide networks. However, as noted above, at most of the surveyed factories, insufficient attention is paid to forging and heat treatment processes, their modes and the carbide structure of fabricated blanks are not controlled. For this reason, in the destroyed sectors of the dies, the carbide inhomogeneity severity is quite high and corresponds to 5-7 points, while according to the technical conditions of factories the carbide inhomogeneity should not exceed 3-4 points. It is characteristic that these carbides mainly consist of weakly deformed networks of eutectic coarse carbides (Figure 3, 4). Their distribution in the form of a network even more worsens the properties of steels, especially impact elasticity, and this is an undesirable factor for cutting parts of dies. The material of the cutting parts, at enough high hardness, must also have a sufficiently high impact and static strength.

## 4. CONCLUSIONS

1. Thus, one can conclude that the main reason for the premature failure of dies due to the fault of the material is a carbide inhomogeneity, a large severity, i.e., graininess of carbides, the presence of coarse precipitates of non-metallic inclusions, as well as a pronounced heterogeneity of the steel structure. These shortcomings can be largely eliminated by using powder metallurgy technology in the production of die steels for various purposes.
2. At that, chip waste of these steels can be successfully used to reduce the prime cost of production of powder die steels. By transforming the chips formed during the machining of blanks of die steels into powder, it can further be compacted both by cold pressing and by highly effective methods of cold and hot compacting, bringing it to a non-porous state. In the future, this approach can successfully compete with the traditional production of powder die steels.

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