UDC 621.7.011:621.9.073

Nitride Die Steel

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Precipitation nitride-vanadium hardening improves effectively volume functional properties of die steel and properties of nitration case, in particular strength, high-temperature stability, temperature resistance and wear resistance. It provides raise of durability of automatic metal forming machine and die molds of non-ferrous alloys in 2-3 times even at replacement of more alloyed die steels.

Keywords: DIE STEEL, PRECIPITATION NITRIDE-VANADIUM HARDENING, NITROGEN HARDENING, PROPERTIES, OPERATING LIFE

Introduction

One of the most widely applied methods to raise operating life of automatic metal forming machine is face nitrogen hardening ensuring increased hardness, high-temperature stability, wear resistance and corrosion stability of surface [1].

According to classical theory of nitride hardening, functional properties of diffused layer are enhanced during steel alloying by active nitride-forming elements (V, Nb, Ti, Al) and elements reducing diffusibility and raising high-temperature stability of alloyed iron nitrides and special nitrides in diffused layer (Mo, W) [2]. Introducers of nitride die steel of series BIS applied this method. In these steels increase of functional properties is achieved only due to additional alloying by vanadium and molybdenum [3, 4]. Alloying of these steels by 0.02-0.08 % Ti and 0.01-0.04 % Al does not have a considerable effect on properties of nitration case as it is known to reveal at aluminum content to 1 % and titanium content to 0.12-0.16 % [5].

Much more effective method to enhance volume functional properties of die steel is nitrogen microalloying and additional precipitation nitride hardening considered in work [6]. This method enables to reclassify steel 5ХНМ(Л) as average heat stability group instead of low heat stability group without decrease of viscosity in casting and forged pieces (steel 5ХНМАФ (Л), and steel 30Х5МАФ can replace almost all steels from high heat stability group including such high-alloy as 45Х3В3МФС (Ди -23) and 3Х2В8МФ. Besides, it is shown in [7] that this method enables to eliminate molybdenum alloying of steels, in which molybdenum does not participate in the process of precipitation carbide hardening but only enhances thermal and reversible temper embrittlement resistance. In particular, molybdenum-free steel 5ХНАФ (Л) is not worse than steel 5ХНМАФ (Л) and much better than steel 5ХНМ(Л) by functional properties.

Results and Discussion

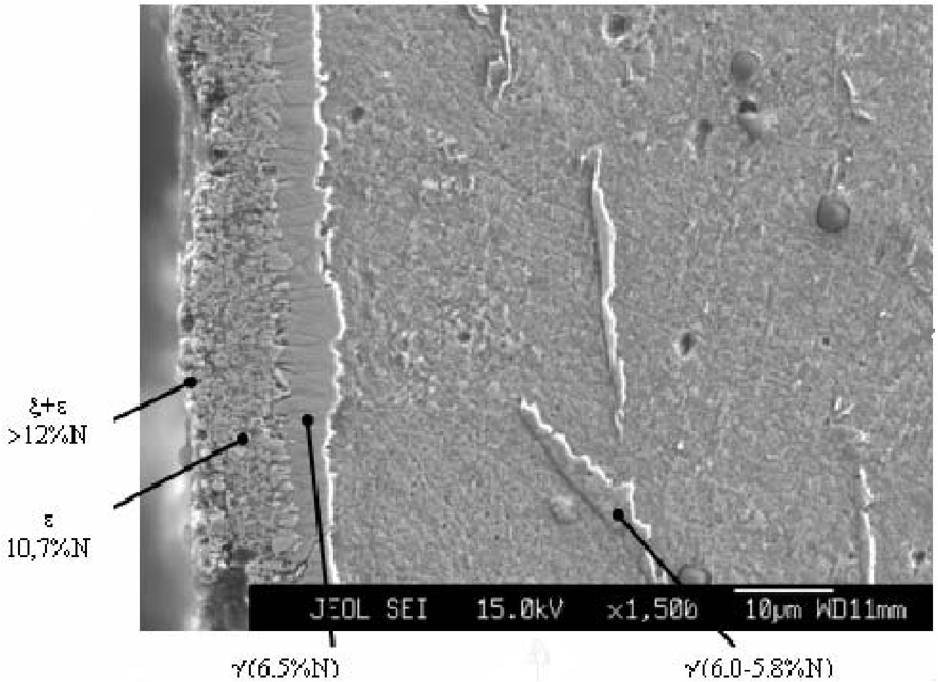
The results of investigation presented in this paper show that precipitation nitride hardening method is very effective and raises functional properties of diffused layer at face nitrogen hardening.

Nitride hardening of steel 30Х5МАФ and similar steel 30Х5МФ without nitride hardening as well as model alloys iron and iron-vanadium-nitrogen was carried out in electric pit-type heating furnace for gas nitrogen hardening США (SShA) - 6.6/7 in the environment of ammonia at 550 °C, degree of ammonia dissociation 25-30 % and gauge pressure 961 Pa. Preliminary heat treatment of samples included oil quenching and high tempering on the maximum heat stability.

Nitride-vanadium phase increases width of nitride zone by 25-100 % from ξ (Fe_2N) + ε (Fe_{2-}

$_3$N) - ε- and γ ` ($Fe_4N$) - phases, decreases porosity of ε - phase and changes form of porosity from closed network of channels in separate dot pores; leads to dispersion of structural components in nitride layer and in internal nitrogen hardening zone; increases nitrogen content in ξ + ε - ε - and γ ` - phases (**Figure 1**). Structure and phase composition of nitration cases were investigated on electron scanning microprobe analyzer SUPERRPROBE JXA - 8200 by JEOL Ltd (Japan).

Increase in width of nitride zone is related to growth of nitrogen concentration in the surface area by diffusion "catchers" which are phase boundaries vanadium - matrix and zones of matrix distorted lattice near vanadium particles [8].



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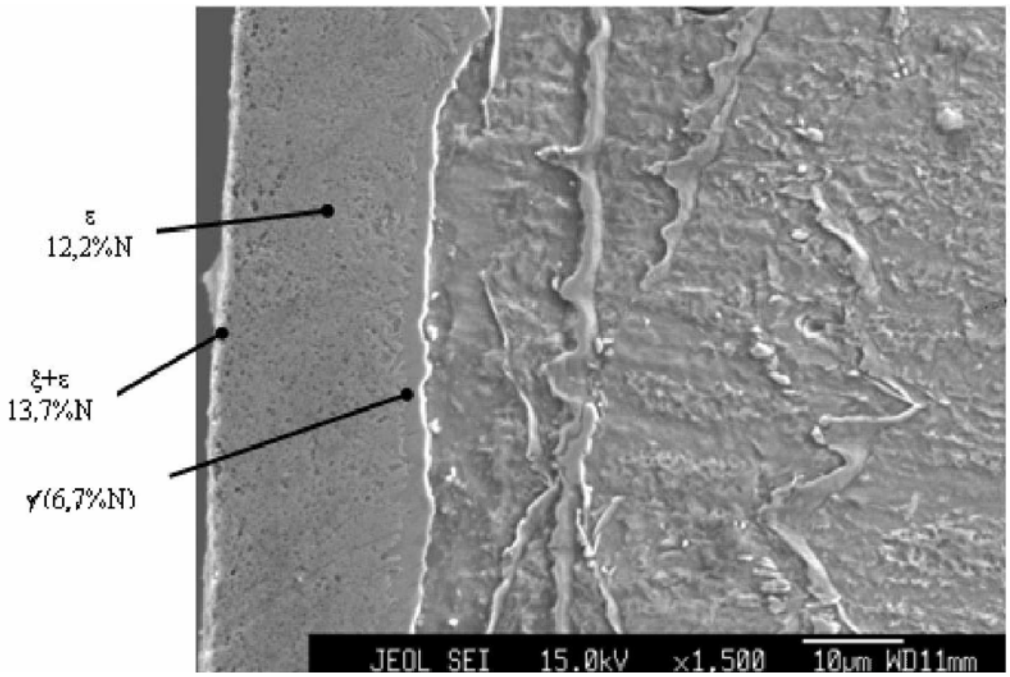

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Figure 1. Structure and phase composition of nitration cases of model alloys Fe (*a*) and Fe-V-N (*b*) (x1500)

Reduction of ε - phase porosity and change of its form is related to increase of number of energetically favorable places of pore origin - intercrystalline and phase boundaries at refining of ferrite grain and dispersion of martensite decomposition products in it, dispersion of substructure and raise of dislocation density in matrix.

Substructure dispersion (size of coherent scattering blocks reduces from 150 to 60 nanometers) and raise of dislocation density from $1.2\cdot10^{11}$ to $4.9\cdot10^{11}$ cm^{-2} in nitride layer provides raise of microhardnesses by 2-5 GPa throughout the cross-section. It is known that in most cases nitrogen hardening raises the total (volume) strength of steels but essentially reduces volume ductility and viscosity. Precipitation nitride hardening increases effect of bulk strength increase during nitrogen hardening (incrementation of σ_{TS} grows from 4 to 7 %) and, which is very important, reduces extent of decrease of volume ductility and viscosity. For example, the extent of δ decrease reduces from 28 to 13 % and impact strength from 33 to 17 %, i.e. approximately in 2 times. The latter is a result of raise of nitride layer crack resistance. Factor K_{Ic} of nitride layer, defined by Evans-Charlz indentation method [9], raises in 1.5-2 times on all cross-section of layer from 1-5 $MP\cdot m^{0.5}$ to 4-8 $MPa\cdot m^{0.5}$. Raised viscosity of nitride steel with precipitation hardening reduces possibility of emergency brittle fracture of dies, especially, hammer ones.

Durability of forming machine tool is defined primarily by high-temperature stability, heat stability and wear resistance of die steel. Precipitation nitride hardening of steel raises the level of these characteristics in nitride layer. So, higher microhardness of layer is maintained when heating at 650 °C (**Figure 2**), and at temperature cycling by regime 650 °C↔40 °C (water) quantity of cycles prior to crack formation raises from 360 to 750, quantity of cycles prior to start of nitrided layer breakaway raises from 540 to 970, intensity of layer breakaway decreases almost in 4 times and rate of crack propagation reduces in more than 10 times.

The raised strength and heat stability of nitride layer provides increased wear resistance. So, at dry sliding friction (counterface steel 60Г with hardness HRC 60, rate of mutual displacement of sample and counterface is 63 $m\cdot min^{-1}$, force 20 H, pressure 0.196 MPa) with local heating-up of nitride layer to temperature higher than 730 °C which is proved by austenite layer formation in case-hardened steel at similar parameters of tests, wear rate drops in 1.5 times in the area of nitrogen solid solution in ferrite (α-phase) and in 3-4 times in nitride layer (**Figure 3**).

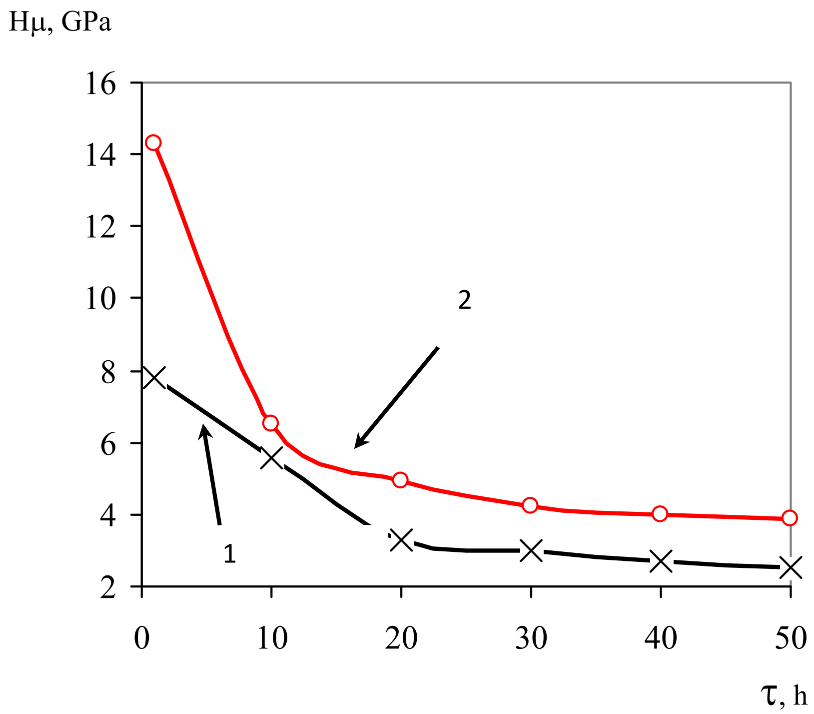

Figure 2. Effect of heating time at 650 °C (τ) on nitride layer microhardness at a depth of 50 microns from the surface of steels 30Х6МФ (*1*) and 30Х6МАФ (*2*) ($T_{hardening}$ = 550 °C; $\tau_{hardening}$ = 38 hours; h_{layer} ≈ 200 microns)

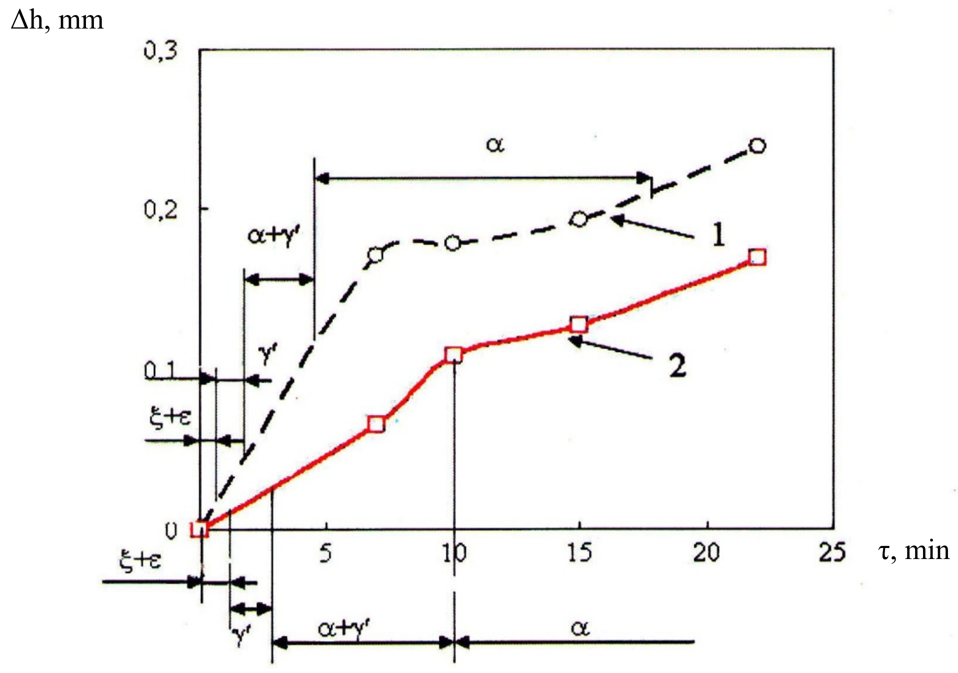

Figure 3. Dependence of wear rate (on depth of deterioration Δh) at dry sliding friction on test period (τ) and phase composition of nitride layer of steels 30Х6МФ (*1*) and 30Х6МАФ (*2*)

Conclusions

Presented results of investigation and industrial adoption show that precipitation nitride-vanadium hardening is effective method to raise functional properties of nitride die steel and operating life of forming machine tool by technical-and-economic indices.

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* Published in Russian

Received May 28, 2010

Азотируемая штамповая сталь

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Дисперсионное нитридванадиевое упрочнение эффективно улучшает не только объемные функциональные свойства штамповых сталей, но и свойства азотированного слоя, в частности прочность, тепло-, термо- и износостойкость. Это обеспечивает повышение в 2-3 раза долговечности кузнечно-прессового инструмента горячего деформирования и пресс-форм литья под давлением цветных сплавов даже при замене более легированных штамповых сталей.