MATHEMATICAL CORRELATIONS BETWEEN THE MAIN ALLOY ELEMENTS AND THE STEELS RESISTANCE

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ABSTRACT

Dissolving in iron, the alloy elements influence the range of austenite and ferrite. In point of influence they have over the allotropic transformation of iron, the alloy elements in the chemical composition of steel type 15VMoCr14X split into two large groups: gamma forming elements (nickel, manganese, carbon, nitrogen etc.) and alpha forming elements (chromium, molybdenum, vanadium, silicon, aluminum).

The alloy elements increase the tensile strength, but differently: Cr, Mo and V increase the resistance of ferrite less than Si, Mn and Ni. The Si, Mn and Mo decrease the resilience of ferrite, more than Ni and Cr do.

In this paper we suggest a mathematical shaping of the influence of the main alloy elements over the resistance characteristics of steel type 15VMoCr14X. It has been noticed that the alloy elements increase the tensile strength, but differently: Cr, Mo and V increase the resistance of ferrite less than Si, Mn and Ni. The Si, Mn and Mo decrease the resilience of ferrite, more than Ni and Cr do. The increase of the alloy content over 1.2% leads to a sudden fall of the resilience. The exception of this rule is nickel that both increases the resilience of ferrite and decreases the transition temperature.

Key words:
alloy elements, mechanical characteristics, mathematical shaping

1. INTRODUCTION

Most of the alloy elements dissolve in ferrite, in big proportion, forming solid substitution solutions, except for carbon, nitrogen, hydrogen and boron that have atomic radii less than those of iron and form interstitial solutions. Some elements (like nickel and cobalt) form isomorphous series of solid solutions, in any proportion, from the melting temperature to the ambient temperature; and others (chromium, molybdenum, vanadium) form, at high temperatures, solid solutions, having unlimited solubility and, when cooling, they form chemical compounds. When solid solutions are formed, the chemical properties, especially, modify and, when chemical compounds (carbides) are formed, the mechanical properties modify.

Many alloy elements, holding higher affinity with carbon than iron, dissolve in cementite, being capable of forming both alloyed cementite and special carbides. The elements situated at the left of iron in the periodical system of elements (Cr, Mn, Mo, V, etc.) form carbides. The elements that hold higher affinity with oxygen than iron form oxides. When processing steel, as a result of the oxidation process, the oxides Al_2O_3, V_2O_5 and SiO_2 can be formed. The alloy elements that hold higher affinity with sulphur than iron form sulphides (MnS, etc.). Usually, the quantity of oxides and sulphides is small because the proportion of oxygen and sulphur is strictly limited at the alloyed steel.

Dissolving in iron, the alloy elements influence the range of austenite and ferrite. In point of influence they have over the allotropic transformation of iron, the alloy elements in the chemical composition of steel type 15VmoCr14X split into two large groups: gamma forming elements (nickel, manganese, carbon, nitrogen etc.) and alpha forming elements (chromium, molybdenum, vanadium, silicon, aluminum).

The alloy elements increase the tensile strength, but differently: Cr, Mo and V increase the resistance of ferrite less than Si, Mn and Ni. The Si, Mn and Mo highly decrease the resilience of ferrite, more than Ni and Cr do.

Manganese and nickel have the greatest influence over the decrease of elongation per unit length. The increase of the alloy content over 1.2% leads to a sudden fall of the resilience. The exception of this rule is nickel that both increases the resilience of ferrite and decreases the transition temperature.

Chromium is an alfa favoring element that, when over 12%, determines the disappearance of the γ-α range. It dissolves both Feα and Feγ, forming especially simple and double carbides, when the carbon content is sufficient. The chromium-based carbides have a higher thermal stability and it is necessary for the austenitic transformation to be made at high temperatures, as well as a long maintenance so that hardening can be possible.

The hypoeuctoid chromium alloyed steel types have a reduced harden-ability because they always contain a bigger quantity of proeutoidic ferrite.

Chromium is characterized by high temper and by the fact that it forms stable carbides that give steel high resistance to wear and makes it suitable for steel cutting. The hardening of alloyed steel is accompanied by a certain loss of its resilience and elongation per unit length. For increasing the resilience and the elongation per unit without decreasing the temper too much, nickel is added in the chemical composition of steel.

Chromium determines an increase in the steel hardening, being the third most used element, after manganese and silicon, the most used chromium alloyed steel types being the perlitic ones. We can say that:

- Chromium content lower than 1% favors the steel hardening.
- Chromium content of 1...3% increases the resistance to hydrogen under pressure and favors the nitrification process.
- As the chromium content increases, the steel becomes more and more resistant to oxidation and corrosion.
- Chromium content higher than 30% determines steel to become infusible.
- Chromium increases the temper and the resistance to wear but decreases the resilience (tenacity).

Molybdenum is an alpha favoring element, just like chromium, but weaker than silicon. The austenite range of steel is restrained in the presence of molybdenum, becoming closed at concentrations higher than 2% Mo, raising the eutectoid transformation temperature and moving it when the carbon content is lower.

Dissolved in ferrite, molybdenum hardens it and increases its resistance to creep. Molybdenum is a chemical element that reacts with carbon, forming complex iron and molybdenum carbides, even when the molybdenum content is low (0.5% Mo).

Molybdenum is twice more carbide favoring than wolfram and its diffusion speed in austenite is four times higher. This property, that determines a better homogeneity when in hot condition, determines a better machinability and tenacity of medium-carbon steel and high-carbon steel but also a higher sensitivity to the thermal treatment and decarburization.
Molybdenum very much lowers the martensitic transformation temperature (Ms), to 1.5% Mo, and decreases the softening tendency when tempering of the hardened steel types, even when the Mo content is only 0.2%.
When tempering the molybdenum alloyed steel types, it takes place a finely dispersed precipitation of some constituents similar to carbides that cancel the tempering brittleness effect, the steel types with 0.5% Mo content not having this effect anymore. Usually, molybdenum is used as an alloy element along with other elements, at processing the alloyed steel types.
Vanadium lowers the austenitic range of the iron and carbon alloys, the iron having 1% vanadium no longer suffering the transformation of α into γ. Vanadium is a highly carbide favoring element, having little stability in cementite and forming very fine vanadium carbides that have a very high hardness and hardly dissolve in austenite when heating it. That is why the vanadium alloyed steel types have a fine structure and resistance to overheating. At very low concentrations (0.04% V), vanadium very much influences the harden-ability, and at higher concentrations and at the usual hardening temperature, it decreases the harden-ability by forming sparingly soluble carbides.
Because of its capacity of forming stable nitrates with nitrogen, vanadium decreases the aging tendency of steel, especially at the extra-soft steel types, for the cold flow. At the semi-soft steel types, vanadium increases the hot flow resistance and the elastic limit.
Vanadium holds a relatively low affinity with oxygen, which means that vanadium is a weak deoxidizer, the deoxidizing effect being stronger at higher vanadium concentrations. That is why the vanadium alloying should be made at smelting, after the deoxidization was performed, in order to eliminate any loss that might occur, vanadium being a very expensive element.

2. THE RESULTS OF THE EXPERIMENTS

The chemical composition of type 15VMoCr14X steel is shown in Table no.1.

Table 1

Chemical composition, [%]	C	Si	Mn	P	S	Cr	Mo	V	Cu	Ni
Requested	0.12…0.18	max. 0.20	0.8…1.10	max. 0.02	max. 0.015	1.25…1.50	0.80…1.00	0.20…0.30	max. 0.16	max. 0.30
Obtained	0.18	0.09	0.86	0.006	0.015	1.50	0.92	0.30	max. 0.16	-

The requested values of the mechanical characteristics, compared to those obtained as a result of laboratory tests, are shown in Table no. 2.

Table 2

Mechanical characteristics	$Rp_{0.2}$ [N/mm^2]	Rm [N/mm^2]	A_5 [%]	WU_5 [J]	KCU_5 [J/cm^2]	$R_1 \cdot 10^{-7}$ [N/mm^2]
Requested	930	1080…1280	10	39	80	500
Longitudinally	1153…1170	1240…1238	17.5…15	54.8…55.8	140…152	550
Transversally	1148…1152	1230…1240	15.75…17.5	47.1…48.1	72…50	510

For the statistical and mathematical analysis, there were used 50 industrial batches.

The average values and the average square aberration of the variables are:

Cr	1.4554	0.0762
Mo	0.8611	0.0143
V	0.2311	0.0155
Rm	1173.11	57.1896

Next, there are shown the results of the multidimensional processing of experimental data. For that purpose, we searched for a method of modeling the dependent variables depending on the independent variables x, y, z:

$$u=c_1 \cdot x^2 + c_2 \cdot y^2 + c_3 \cdot z^2 + c_4 \cdot x \cdot y + c_5 \cdot y \cdot z + c_6 \cdot z \cdot x + c_7 \cdot x + c_8 \cdot y + c_9 \cdot z + c_{10} \qquad (5)$$

The optimal form of modeling, studied on a sample of 50 batches is given by the equations:

$$Rm = 252.2642 \cdot Cr^2 - 2.5251 \cdot Mo^2 + 9.4122 \cdot V^2 + 2.3667 \cdot Cr \cdot Mo + 7125 \cdot Mo \cdot V - 4.8941 \cdot V \cdot Cr - 1.0424 \cdot Cr + 7486 \cdot Mo + 2.2014 \cdot V + 3367 \qquad (2)$$

where the correlation coefficient is:

$$r = 0.7489 \qquad (3)$$

and the aberration from the regression surface is:

$$s = 37.8943 \quad (4)$$

This surface from the four dimensional space allows a saddle point having the following co-ordinates:

$$Cr_ş = 2.2062$$
$$Mo_ş = 1.2399$$
$$V_ş = 0.4093$$
$$Rm_ş = 1016$$

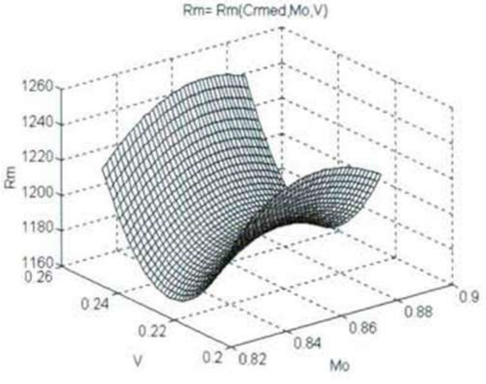

Figure 1. The surface $Rm = Rm(Cr_{med}, Mo, V)$

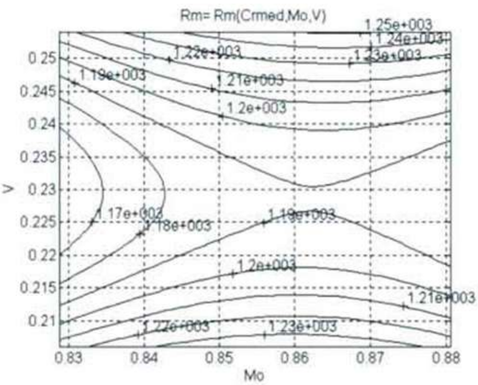

Figure 2. The level curves of distribution $Rm = Rm(Cr_{med}, Mo, V)$

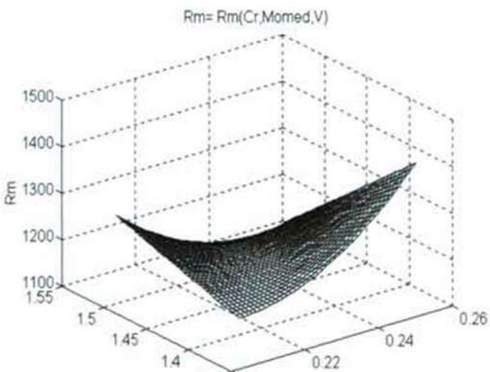

Figure 3. The surface $Rm = Rm(Cr, Mo_{med}, V)$

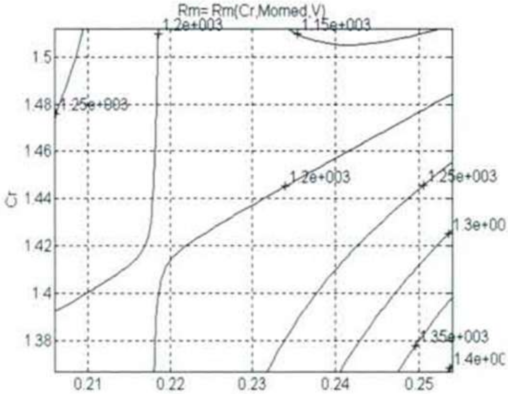

Figure 4. The level curves of distribution $Rm = Rm(Cr, Mo_{med}, V)$

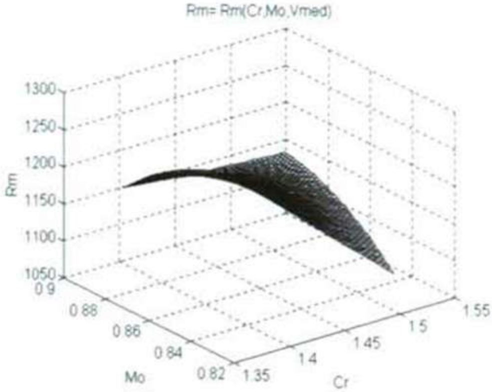

Figure 5. The surface
Rm = Rm(Cr, Mo, V_{med})

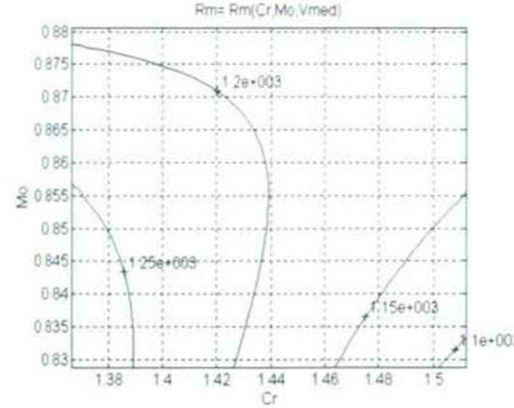

Figure 6. The level curves of distribution
Rm = Rm(Cr, Mo, V_{med})

3. CONCLUSIONS

The behavior of these hypersurfaces in the point where three independent variables take their average value can be studied only tabular (for example, table no.3), attributing values to the independent variables on spheres concentric to the studied point.

Because this surface cannot be represented in the three-dimensional space, the independent variables were successively replaced with their average values.

Table 3

No.	Chemical composition [%]			The tensile strength Rm, [N/mm^2]
	C	Cr	Mn	
1.	1.435	0.861	0.230	1201.1
2.	1.441	0.861	0.244	1230.0
3.	1.455	0.881	0.230	1181.1
4.	1.469	0.861	0.215	1206.8
5.	1.475	0.861	0.230	1178.7

This is how the following equations were obtained.

$$Rm_{(Crmed)} = -2.5277 \cdot Mo^2 + 9.4144 \cdot V^2 + 7125 \cdot Mo \cdot V + 4.1924 \cdot Mo - 4.9168 \cdot V - 1.1266 \quad (5)$$

$$Rm_{(Momed)} = 9.4124 \cdot V^2 + 252.2 \cdot Cr^2 - 4.8914 \cdot V \cdot Cr + 2.8144 \cdot V + 9953 \cdot Cr - 8912 \quad (6)$$

$$Rm_{(Vmed)} = 252.2 \cdot Cr^2 - 2.5254 \cdot Mo^2 + 2.3661 \cdot Cr \cdot Mo - 2.1671 \cdot Cr + 9125 \cdot Mo + 1.3419 \quad (7)$$

These surfaces, belonging to the three-dimensional space, can be represented and, therefore, interpreted by technologists. The surfaces are represented in fig. 1, 3 and 5. For a more correct quantitative analysis, in fig. 2, 4 and 6, there were represented the corresponding level lines, resulting the following conclusions: in the case of $Cr=Cr_{med}$, Rm allows a maximum for Mo=0.86 and a maximum V, and minimum values for V= 0.23 and a minimum Mo; in the case of $Mo=Mo_{med}$ a maximum can be noticed in the area where V=0.26 and Cr is minimum; when $V=V_{med}$ there can be noticed a maximum of Rm for Cr=1.33 and Mo is minimum, the minimum value being reached when Cr is maximum and Mo is minimum.

Knowing these level curves allows the correlation of the values of the two independent variables so that Rm is obtained in between the requested limits.

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