NEW STEELS AND ALLOYS

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During 1960 the I. P. Bardin Central Scientific Research Institute of Ferrous Metallurgy (TsNIIChM) carried out investigations in the following areas: theory of strength; high-strength materials; development and introduction of new steels and alloys for various applications, including some steels which can be economically alloyed with nickel; development of technical processes of hardening by thermal treatment; finding new precision alloys with specific characteristics; industrial application of new methods of analysis, etc.

Theory of strength and the development of high-strength materials. Work was started along a number of promising lines. These included direct observations of dislocations in metals and further development of the theory of such dislocations; study of physical and mechanical characteristics of fine threadlike crystals with a strength close to theoretical; and study of the processes of hardening and softening.

Metallographic, electron-microscopic, and X-ray methods of observation of dislocations have been put on a routine basis. Dislocations and their motion were studied in iron, nickel, and chromium, and in alloys. Methods were perfected for producing microcrystals and for deforming them at low dislocation densities. The resistance of crystalline lattices to the progress of dislocations and the part played by thermal movements in the motion of dislocations were studied.

The work on the investigation of structural characteristics of the hardened state had as its aim the study of the connection between the alteration of fine crystalline structures and the mechanical characteristics after hardening.

Pure metals and binary alloys were studied. It was shown that second-order stresses do not ensure the high strength of hardened materials. The magnitude of the second-order stresses after hardening illustrates the properties of the crystals and thus indicates the degree of elastic deformations in microregions. It was established that variations in the magnitude of second-order stresses on heating correspond to the changes in the limits of ductility.

It was found that the strength of metals and alloys hardened at different temperatures depends on the characteristics of the crystals of the material studied at the given temperatures and on the character of the micro- and submicrostructures formed in the grain. The substructure of hardened materials begins to change at temperatures higher than the temperatures at which the mechanical features of the crystals were established.

Diffusion processes in metals were studied in order to establish the effects of damaged structure. In this direction the effects of small additions of boron and molybdenum were studied, as were effects of the structural state of alloys upon the diffusion of iron. Both boron and molybdenum lower the mobility of atoms of iron along grain boundaries. The relationships thus established permitted calculation of the surface tensions at these boundaries.

It was found that boron and molybdenum lower the surface energy, these effects weakening at higher temperatures. This feature is apparently of a general character.

Theoretical examination of diffusion under load yielded the equation for diffusion under tensile stress. It is analogous to the equation of increasing diffusion proposed by S. T. Konobeyevskiy. It has been established for the first time that in solid solution of the interpenetration type the static shear modulus falls with increased concentrations of additions at small stresses, i.e., an additional deformation takes place due to the migration of the additional atoms.

Parallel with the studies in the theory of strength, investigations were made aimed at the creation of high-strength materials. Among the results were the production of single-crystal threads of iron with an ultimate strength exceeding that of quality steel, and the production of high-strength steel wire and ribbon. Experimental work included a thermomechanical treatment of steels that raises the ultimate strength to 280–300 kg/mm^2.

It has been experimentally shown that high pressures can produce new phases in metallic systems and may make it possible to change the kinetics of transformations.

Producing deformations at very high pressures makes it possible to obtain higher levels of hardening, to increase plastic properties, and to eliminate or decrease brittleness.

Thermal treatment in metallurgical plants. The collective of scientific workers of TsNIIChM, acting in cooperation with the collectives of the Alchevskiy and Novo-Lipetskiy metallurgical plants, is conducting large-scale tests of heat-treating processes and of their introduction into plant processes. Techniques of producing rimming steel in the form of hardened plate were tested on a large scale at the Alchevskiy plant and the product was tested for its application in construction work. An experimental batch of plate steel 3 kp (rimmed) 12–40 mm thick was tested in the hardened state. The sheets were treated in continuous channel furnaces with bottom rollers. The tests showed that sheets subjected to water-jet cooling under pressure process enchanced mechanical properties.

Work is being continued on the precise determination of the temperatures of heated steels and the soaking time. The causes of hardening in "nonquenchable" steels such as steel 3 were investigated. They were found to vary for different rates of cooling. The techniques of the hardening thermal treatment of rods and sheets of carbon steels were studied. It was established that the yield point of such steel in sheet or profiled shapes is 25% higher than of hot rolled steel. In addition to the improvement of mechanical features, thermal treatment of rimming steels eliminates the tendency to age and lowers the threshold of cold brittleness below 0°C.

At the Novo-Lipetskiy plant the technique of sheet rolling in electrical steel of high magnetic quality has been developed and put on a production basis. TsNIIChM proposed a technique of hot drawing for deformation-resistant steels, in particular for high-speed steel, which makes possible wire drawing without the necessity for a number of intermediate reheats. This method has been introduced at many plants. Shortening of the production cycle permitted an increase in production and relieved the furnaces of extra work. Hot drawing cuts down the amount of scrap and raises metal quality.

New steels. The Institute continued its work of creating and introducing specialty steels into industry. Many of these activities were undertaken in cooperation with the collectives of plants and of scientific institutes. In 1960 alone nearly 40 new steels and alloys were adopted by industry.

The new high-strength armature steel 65 GC was developed and industrially adopted as a substitute for steel 30 KhG2S. Examination of periodical profiles 14—18 has shown that 65GS is far less sensitive than the earlier steel to the rate of cooling, and its mechanical characteristics are more uniform and more stable. These characteristics satisfy the specifications of GOST 5058—57.

Armature steels 28GS2 and 15GS were also developed and tested.

Steel 28GS2 is analogous to steel 25GS (GOST 5058—57) but contains less manganese. It has been tested at the Magnitogorsk Metallurgical Combine and at the Chelyabinsk Metallurgical Plant. Study of periodical profile No. 10—32 has shown that this steel fully satisfies the specifications. It welds well and its embrittling temperature is (—) 50 to 60°C.

The development and constructional adapation of low-alloy steel with enhanced characteristics is highly important. To this end the study of steel 14G2 is being continued. Nearly 5, 000 metric tons of this steel went into the metal construction of blast furnaces. The saving of metal achieved by using this steel instead of carbon steel was 15—20%.

Laboratory work by the Institute and industrial tests resulted in three grades of low-alloy steel for use in manufacturing electrowelded tubing of large diameter, especially for ore-deposit drillings in the Orsk-Khalilov mines. Thus, steel 14GN, with a guaranteed ultimate tensile strength of not less than 48 kg/mm^2, has been adopted by tube-rolling plants. Steels 14KhGN and 15GN, with an ultimate strength of 50 kg/mm^2, are being tested for industrial acceptance.

Steel 18G2 was successfully tested for tube-making at the Khartsyz steel plant. It guarantees the safety of gas pipe with an ultimate strength of not less than 50 kg/mm^2.

Tests were made on tubings made of sheet steel 19G, which is produced by cross-rolling and possesses higher plasticity and ductility in comparison to sheets produced by longitudinal rolling. The same steel was also tested for heat hardening qualitites in the making of tubing and for standardization of sheets made from the head slabs of ingots with their increased contents of carbon and manganese. A batch of sheet and tubing made of steel 14G2 and 19GS, ($\sigma_b = 50\ kg/mm^2$), was prepared for industrial tests.

Experimental work was done on industrial testing and adoption of new structural steels, economically alloyed with nickel. Thus, the Minsk Tractor Plant is testing steel 20KhGNR — 20KhNR, proposed by the Institute as a substitute for 20KhNZA. Steel 20KhNR will be used for making parts of the "Belarus" tractor; this should result in a considerable saving of nickel. The testing of steels 40KhGR, 40KhNV for suitability in the starter-shafts of Diesels has shown that the previously used 40KhNM could be replaced by the nickel-free steel 40KhGR, so the latter was adopted for use. New steels 30KhGR and 35KhGR were also tested and the results reported. It was found, in particular, that the addition of 0.06—0.12% Ti to steel 35KhR lowers the temperature coefficient of ductility and increases the tendency to temper-brittleness. Thus, Ti content of structural steels should not exceed 0.05—0.06%.

Nickel-free steel EI958, developed by the Institute for die-work, has been adopted by two plants as a substitute for 5KhNV and 3Kh2V8. The use of EI958 for die-pressing of deformation-resistant alloys increases tool life 2—4 times in comparison to 5KhNM and gives a saving of nickel. Steel EI958 equals steel 3Kh2V8 in wear-resistance, but costs only half as much.

Work is progressing on the development of stainless steels with lower nickel content to replace steels 1Kh18N9 and 1Kh18N9T. This problem was approached from two directions: development of two-phase, ferritic-austenitic steels with a reasonable degree of workability (Kh18T, Kh21T, and Kh28 with small additions of nickel or of nickel plus manganese) and of single-phase austenitic steels with manganese or manganese plus nitrogen substituted for nickel.

As a result of work in the first direction, industrial testing of steels 0Kh21N3T (EP214), 0Kh21N5T (EP53), and Kh21N5T (EI811) was recommended. For technological and corrosion properties, these steels are recommended as substitutes for 1Kh18N9T in various branches of industry. Steel Kh21N6M2T (EP154) was developed as a substitute for Kh18N12M2T (EI448).

Work in the second direction resulted in the development of steels Kh14G14N, (EP212) and Kh14G14N3T (EI711). In workability and other properties these steels are full-value substitutes for 1Kh18N9 and 1Kh18N9T.

Certain steels containing nitrogen 1Kh17AG14 (EP213), 0Kh17N5G9AB (EP55), and Kh20N4G11AB (NN3B) are sufficiently close in chemical resistivity and in technology to steels 1Kh18N9 and 1Kh18N9T and can be substituted for the latter. Their introduction into industry will considerably reduce expenditures for nickel.

Much effort by the scientists of the Institute is directed to the development and industrializing of new heat-resistant steels and alloys. Thus, a heat resistant but ductile alloy has been used for serial production of turbine blades. Alloy EI787 has gained industrial acceptance as a substitute for a nickel-base alloy. The use of this alloy saves 450 kg nickel per ton of metal. The use of heat-resistant steel EI835 likewise effects a saving of 600 kg of nickel per ton of product.

In cooperation with the Central research institute for the mechanical treatment of wood and the Gorkiy Metallurgical Plant, the Institute developed and turned over to the lumber industry the new steels 9Kh5BF and P4 to replace the steels used earlier, KhVG and Kh12F. These steels lengthen by 2—3.5 times the service life of knives, lower the costs of sharpening, increase the efficiency of equipment, and stabilize the normal performance of the work of automated lines. In addition, the new steels permit the treatment of new materials — bricks of compressed wood shavings, glued cellulose, etc. The economic effect of these two steels has been very great. The process of industrializing new high-speed steels is continuing. In June 1961 the new

GOST developed by the Institute went into effect. It contains, in addition to the old, seven new types of rapid-cutting steels of high efficienty which lengthen the service life of tools by 2—3 times.

The investigation covering the selection of the compositions of high-speed steels has been conducted in cooperation with the Central Scientific Research Institute of Technology and Machinery (TsNIITMASH) on the machining of heat-resistant alloys. It resulted in lengthening the service life of tools by 7—8 times in comparison to steels P9 and P18.

Alloys with special properties. Physical properties have been studied especially for alloys used for precision requirements. These were soft or hard magnetic alloys, with specified thermal expansion coefficients, elastic properties, and resistance alloys. More than 30 such alloys were introduced to industry in 1960. The number of alloys studied containing rare elements was greatly expanded, as were the methods conducting these experimental studies. The alloys studied were those in the systems Mn—Pd, Mn—Ge, Ni—Mo, alloys of chromium with nickel, molybdenum, etc.; rhenium and various rare-earth metal additions were not excluded from the list. Processes widely used in research work were: vacuum melting, production of powdered metals from melts, and the rolling and drawing of fine wire and of thin ribbons.

It was found that alloys in the ternary system Ti—V—Mo can yield materials of high specific resistivity plus good corrosion resistance.

Binary and additionally alloyed compositions based upon the Ni—Cr system have high mechanical characteristics when tempered after cold work. Alloys of Ni—Cr—Mo were found to have characteristics of a special spring alloy.

An Fe—Al soft magnetic alloy has been developed with excellent magnetic characteristics, similar to those of high-nickel alloys, but having better features as regards saturation induction, anticorrosive properties, and strength. A somewhat lower aluminum content in comparison to the earlier alloy of this type provides better workability.

This new alloy can be used in cases where corrosion resistance and high strength are required, but nickel-based alloys are contraindicated.

Investigations on the formation of texture in relation to conditions of rolling and thermal treatment resulted in the production of Fe—Si ribbons 0.01—0.1 mm thick with a cube texture and a rectangular hysteresis loop. With this texture the steel possesses a very high initial permeability, and a low coercive force in comparison to steel with a Gosse texture. This cube texture is developed by a final high temperature anneal either in an atmosphere of pure hydrogen or in an extreme vacuum. Study of recrystallization texture and of the anisotropy of alloys with high magnetostriction has shown that a texturized Fe—Al alloy possesses high magnetostriction and can be used in many cases as a substitute for iron-cobalt alloys. A method for the quantitative investigation of textures was perfected.

Studies have been made of the effects of additions upon the physicomechanical characteristics of nonmagnetic alloys for sensitive elastic parts. This resulted in the development and industrial testing of some new alloys. Two new alloys were developed for conductor springs.

Alloys were developed for the production of high-resolution lenses for electron microscopes. The characteristics of previously developed alloys used in welding to glass were investigated. A new glass-weldable alloy for a new type of glass was tested.

An investigation was conducted on the effects of additions on nonmagnetic glass-weldable alloys as substitutes for Kovar (Fernico). New techniques were developed for the production of wide ribbons of alloys weldable to zirconia-based ceramics.

Both previously developed and new alloys of higher specific resistivity, intended for use as strain gages, were studied.

The following studies were performed in regard to magnetic alloys.

The effects of the conditions of magnetizing on the basic character of soft magnetic alloys both in a constant and in a variable magnetic field were determined. The variations of magnetic properties during the process of measurement were studied. This made it possible to propose special instructions on problems encountered in the measurement of magnetic properties.

Changes in properties of soft magnetic alloys after exposure to neutron irradiation in a nuclear reactor were studied. It was found that this irradiation can not only destroy but can also restore the degree of crystal order. The data thus obtained are important in developing alloys that are exposed to such irradiation. A specially developed technique was used to study the magnetic domain structure in Fe—Al and Fe—Si alloys as well as the effects of metallurgical defects, especially nonmetallic inclusions. It was shown that the magnetic structure of a soft magnetic alloy is sensitive to the shape on the particles of the inclusions and to the whole zone of defective structure around such particles. It was found that the dimensions of such zones could be 10—15 times greater than the dimensions of the inclusion. The results obtained will form a basis for the rationalization of the technique of producing Fe—Al and Fe—Si alloys.

This work was followed by the development of new alloys with high magnetic properties. After studies of crystallization processes and zone-melting techniques specimens with the stipulated unique magnetic properties were obtained. These alloys can be used in designing light-weight electrical generators.

A large part of the work of the Institute directed to the development of alloys for precision needs consisted of theoretical work. Relationships among the magnetic, elastomagnetic, and elastic energies, and the crystallographic lattice units, and the properties of single and polycrystals were investigated. Included in the results were data on the elastic properties of single crystal Fe—Ni alloys and on the relations between the elastic properties and direction in the crystals. The anisotropy of the elastic properties in single crystals was examined.

Study of the causes of the linear relationship between induction and temperature in the vicinity of the Curie point in thermomagnetic alloys raised the possibility of connecting this anomaly with microinhomogeneities. A study was made of the mechanical features of highly ordered alloys. It was established that tempering affects the mechanical features of alloys of long-range order to a greater extent than disordered alloys.

Theoretical investigation of constitutional diagrams for alloys of the face-centered cubic lattice, but with superstructures, showed that the experimentally determined diagram can coincide with the theoretical only when the processes of order are taken into account. The same analysis showed that with sufficiently strong supercooling the disorder—order change may proceed without the preliminary formation of nuclei.

An investigation of spontaneous magnetizing in single and polycrystals at low temperatures and high pressures was initiated. The "Elektrostal'" plant subjected to industrial testing the Alfenol alloy (Fe—Al), which was developed by the Institute and has high mechanical and magnetic characteristics. The alloy can replace the usual permalloy used in the heads of magnetic recording instruments.

Ten watch and clock factories began to use for hairsprings a dispersion-hardened alloy which improves the action of their chronometers. The temperature error of watches provided with such hairsprings is less than 0.5 sec/degree/day.

Specimens of nichrome with improved properties were also tested industrially. This was done with the cooperation of OKB "Elektropech'" (electric furnace) and the "Elektrostal'" plant. The new alloy has been accepted by the industry for heaters working at 1200°C and having a longer service life.

In 1960 the instrument-making industry adopted more than 30 new precision alloys developed by TsNIIChM.

Research methods and instruments. The year 1960 has seen a continuation of development work in methods of testing and experimenting by the introduction of electronics.

Equipment for experimentation at high pressures was developed and perfected. A unique installation for neutron-structural analysis was developed. It permits neutronograms of single and polycrystals to be obtained in a magnetic field, at varying temperatures and high pressures. A basis of thermodynamic investigation was evolved and methods of studying the effects of irradiation perfected.

A sample instrument was built which greatly reduces the quantity of radioactive isotopes it is necessary to introduce into an open hearth furnace for studying the technological process.

MECHANISM AND KINETICS OF PHASE TRANSFORMATION IN CAST IRON

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Phase transformation in cast irons on solidification. In the solidification of cast iron, austenite, graphite, and cementite may form. According to the composition and conditions of crystallization, these phases may form separately or simultaneously. In a separate development the crystals of austenite form dendrites with branches running in three perpendicular directions parallel to the directions of the cube (Fig. 1a).

Graphite may grow in the melt in the form of either plates (Fig. 1b) or spheroidal inclusions (Fig. 1c). In the first case the growth is highly anisotropic. Longitudinal growth of the plate is rapid, while thickness increases slowly. The result is maximum growth in the basal plane (0001) with low surface energy. The edges of the platelets, where the strong covalent bonds of carbon do not become saturated, possess large surface energy.

Cast irons modified by magnesium form spheroids of graphite which are polycrystalline bodies built of pyramidal crystals. Their vertices meet at the centers of the spheroids. It has been found that in crystalline substances with large differences between the surface energies of different planes, the free energy of the polycrystalline body may be lower than that of single-crystal, especially if the polycrystal is surrounded mainly by planes of low surface energy [1], [2].

Reports [3] and [4] show that cementite grows in the melt in the shape of thin plates by the spread of flat dendrites (Fig. 1d). The branches of the dendrites grow at maximum speed in the directions of the a and b axes of the orthorhombic lattice of cementite (longitudinal spread). The thickening of the plates in the direction of the c-axis (cross-spread) takes place slowly. This type of growth ensures the development of surfaces of low free energy.

The sequence of the separation of austenite, graphite, and cementite during isothermal crystallization depends on the composition, previous treatment, and degree of supercooling of the melt.

For hypoeutectic compositions differing greatly from the eutectic, the relative positions of the lines of the beginning separation of austenite (line OZ), of graphite (line BF), and of cementite (line NI) are shown in Fig. 2a. At all temperatures below the liquidus point (T_1), austenite separates first.

The possibility of crystallization of graphite and of cementite appears at temperatures below the upper limit of the interval of eutectic equilibrium ($T_2 - T_3$). In cast irons close to the eutectic composition, the sequence of phase crystallization depends on supercooling (Fig. 2b).

At temperatures above T_4 crystallization begins with the separation of graphite. For temperatures between T_4 and T_5, it begins with that of austenite, and at temperatures still lower with that of cementite. As a result eutectic cast iron can have a hypo- or a hypereutectic structure, or both (Fig. 3). It depends on the nature of the primary crystals formed and on the degree of their growth in the melt before the simultaneous formation of the phases forming the eutectoid begins. Slightly hypoeutectic alloys crystallizing with little or much supercooling may have a hypereutectic structure, while hypereutectic compositions