both for normalized steel (Figure 5) and for high-temperature temper quenched steel (Figure 6).

As it follows from presented in the Figures correlation factors, value of ratio R / σ_y for all experimental dependences exceeds 3, which corresponds to the level of fiduciary probability of the data obtained ($\alpha \geq \geq 0.95$) and is rather high value for multifactor investigations. This allows speaking about high statistic reliability of the data obtained and predicting their reproducibility in melting of the 20GL steel with CNH in industrial furnaces.

CONCLUSIONS

1. Modification of the 20GL ferrite-pearlite steel by titanium, aluminium and nitrogen in combination with rather narrow ranges of content of base elements (silicon, manganese and carbon) corresponds to the level of requirements, established for cast elements of freight railway cars of new generation.

2. The results obtained have high statistic reliability and are accepted for industrial application.

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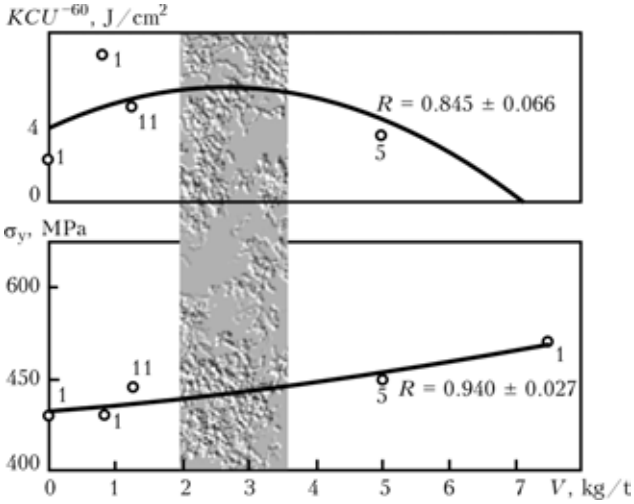

Figure 6. Influence of ALK consumption V on yield strength and impact toughness of high-temperature temper quenched 20GL steel

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ANALYSIS OF TECHNOLOGICAL DEVELOPMENT OF FINISH METAL PRODUCT TREATMENT

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Review of existing in the world methods of the rolled metal heat treatment and technological directions of coating application on metal products is made. Results of technological development analysis of finish metal product treatment are presented. The most rational technological schemes of finish metal product treatment are suggested.

K e y w o r d s : heat treatment, quality metal product, anticorrosion coatings, controlled rolling

Intensive development of construction and automotive industry within postwar period up to nowadays required high amount of quality metal products.

Improvement of the rolled stock quality is to a significant degree ensured in the process of the fourth metallurgical process stage (heat treatment, heat hardening, and application of protective anticorrosion coatings).

Quality metal product is rather wide idea. One of its components is rolled stock from alloyed, low-alloy, carbon and low-carbon steels, produced by the method of controllable rolling, heat treated in separate units after rolling, subjected to heat treatment in rolling heating, with metal or non-metal coatings. Growth of volume of production of quality steels is presented in Figure 1.

Special attention has to be paid to wish of the metal product consumers to get it in the form, suitable for manufacturing of their products.

That's why metallurgical plants try to produce rolled stock with preset properties –– a combination

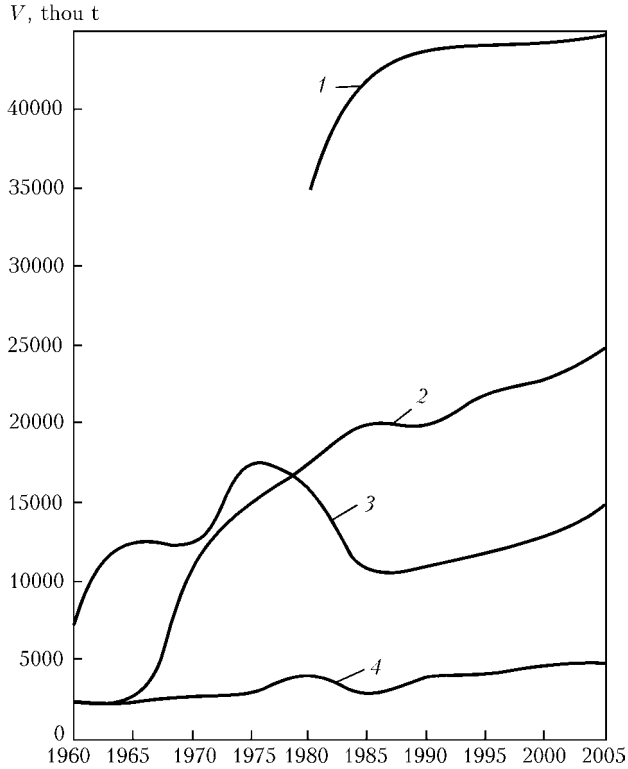

Figure 1. Volume *V* of quality steel melting in economically developed countries; here and in Figures 2 and 3: *1* — USA; *2* — Japan; *3* — France; *4* — Brazil

of the required values of strength, ductility, and service characteristics.

Mentioned changes in conditions of the metal product supply are based on radical perfection of the metal production at the ferrous metallurgy plants. From this viewpoint of great significance is registered in a number of countries transition from production of relatively high-alloy structural steels, subjected to heat treatment at a metallurgical plant or at the enterprise-consumer of this metal, to production of high-strength rolled stock without application of separate heat treatment and with minimal content of alloying additives.

Mentioned statement should not be interpreted as refusal of metallurgists from application of the metal heat treatment as a measure for improving mechanical and technological properties. Development of processes in ferrous metallurgy follows at present the way of achievement of the required results using simpler, cheaper and, as a result, more rational methods, while heat treatment may be used in order to meet more strict requirements, for example in production of heavy-duty steels [1].

Technologies of metal product finish treatment based on processes of heat treatment. Improvement of the steel rolled stock mechanical properties is frequently achieved due to application of controllable rolling, at which hot deformation (and for rolled stock in reels or rolls also reeling) is performed under strictly regulated temperature conditions. Significant share of general reduction is performed at the temperatures below the level of austenite transformations. So, the controlled rolling is actually thermomechanical treatment of the metal.

It should be noted that effect of the controlled rolling is connected with special change of steel microstructure and is manifested provided certain conditions are observed, main of which is that the steel has to be clean in regard to sulfur and non-metal inclusions. The highest effect is achieved on oxygen-converter steels that passed out-of-furnace treatment.

In production of coiled steel on broad-strip continuous mills a regulated rolling is used. In this case intensity of cooling and temperature of the strip reeling into rolls are strictly controlled [2].

They started to use controlled rolling in industry in 1960s on plate mills. Later they started to use it on broad-strip and section mills. At big metallurgical enterprises about 20 % of produced plate rolled stock are subjected to the controlled rolling.

At present mentioned processes are used at such state-of-the-art metallurgical enterprises as inter-branch regional centers of thermal metal products [3].

Methods of application of protection coatings on final metal products. More and more frequently ferrous metallurgy assumes function of finishing of the rolled stock surface. This is explained by high efficiency of continuous application of coatings on a steel strip. Application of coatings serves first of all for long-term protection of metal products against corrosion. In addition, steels with coatings are imparted decorative and special properties. Surfaces of sheets and strips from corrosion-resistant steels and aluminium are also subjected to finishing. Among methods of production of steel corrosion-resistant products at enterprises of ferrous metallurgy production of rolled sheet with coatings occupies first position.

Sheet metal with coating. Tinplate occupies first position as to the volume of its production. In Figure 2 data on production and consumption of tinplate in capitalist and developing countries within 1980--2005 are presented [4, 5]. As one can see from the Figure, production of tinplate in developing countries increases every year.

The biggest producer of tinplate and sheet metal as a whole continues to be the USA despite reduction of volumes of production in comparison with the maximal achieved level (6.2 mln t in 1968) [6]. In 2003 general dispatches of sheet metal constituted 3684.7 thou t. In Japan (second position in the world in regard to production of tinplate and coated sheet metal as a whole) volume of tinplate production in 1997 constituted 1977 thou t, and in 1980s it somewhat reduced [7]. The biggest in the world exporters of tinplate are Japan (48.2 % in 2002), in Western Europe ---- France, FRG and Netherlands. Great Britain achieved maximal volume of tinplate production in 2001 ---- 1283 thou t.

Volumes of production of hot-dipped tinplate, used in canning industry, are significant only in countries of former socialist camp, but nowadays process

of their reduction is registered. Production of hot-dipped tinplate in industrially developed capitalist countries in some cases revives, although it is not used anymore in canning industry.

Production of chrome-plated sheet metal is stable or increases in the producer-countries. Although in the USA it is lower than maximal achieved level (1.2 mln t in 1973), from 1995 on it was rather constant, in particular, 850 thou t / year. In 2000 its dispatched volume constituted 857.1 thou t, in 2003 ---- 1041.8 thou t. Leader in production of chromium-plated sheet metal at present is Japan, where production increases at high rate and constitute at present approximately 1.2 mln t, whereby 25 % of chromium-plated sheet metal are exported.

Rolled sheet with galvanized coatings from zinc alloys. To the galvanized rolled sheet relates rolled metal with coatings from zinc and its alloys, which are applied by method of dipping into the melt (hot-galvanized, with thermal diffusion coating by iron-zinc alloy, with coatings from alloys of zinc with aluminium (4.5–5.0, 15, 30 and 55 wt.%) and small additives of other elements), coatings produced by electrolytic method (zinc ones, from alloys of zinc with iron, nickel, manganese, and other types including multilayer ones, in which zinc is present in one or two layers). Zinc may be also applied on a steel strip by deposition from vapor phase in vacuum, but this technology is still rarely used.

Growth of the galvanized rolled sheet production in main capitalist countries in 1980–2003 is shown in Figure 3. In Japan its volume in 1986 constituted 9088 thou t, in 2002 ---- 18197 thou t, i.e. it continues to increase.

According to estimation, made in 1981, annual volume of subjected to galvanization ferrous metals constituted all over the world about 35 mln t (about 3 bln m^2 of surface) [8].

In FRG about 150 enterprises applied in 1979 for protection against corrosion coatings on 3 mln t of ferrous metals (approximately 270 mln m^2 of surface). Consumption of zinc for hot galvanization constituted about 165 thou t, about 70 thou t of which were used for piece galvanization, approximately 10 thou t ---- for galvanization of wire and pipes, and about 75 thou t ---- for galvanization of strips [9]. Volume of production of hot-galvanized sheets and strips in this country in 1979 constituted about 1.49 mln t, in 1990 and 1995 ---- 1.5 mln t. Volume of production of hot-aluminized strips, and sheets and strips, produced by the method of dipping into a melt, constituted in 1985 1.7 mln t, and their share in general volume of production of thin sheet in the country equaled more than 20 %. Beginning from 1959, from eight installed broad-strip units for application of coatings by the method of dipping into a melt at present only six operate and produce about 8 % of the products, produced at almost 200 known in the world broad-strip units for application of coatings by the method of dipping into a melt [10].

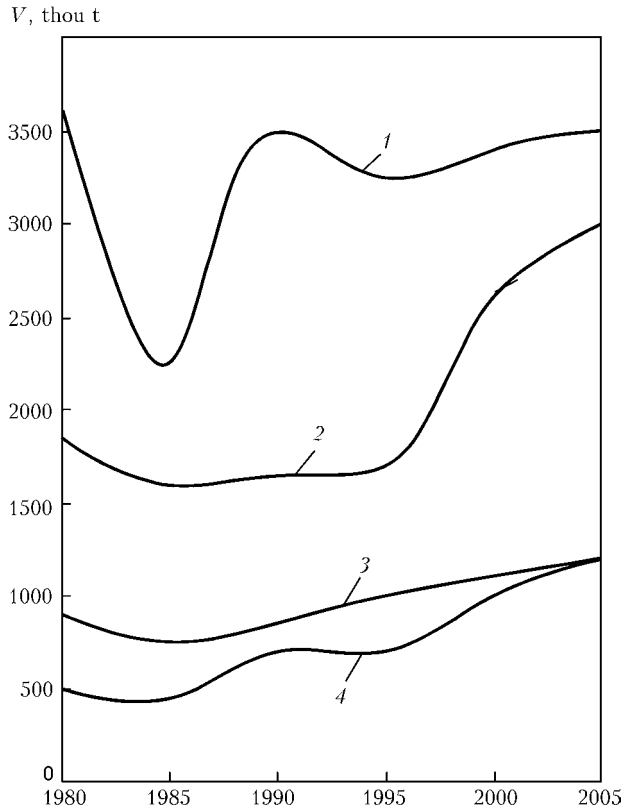

Figure 2. Volume of tinplate production in developed and developing countries

As it follows from [11], general volume of produced in the world beginning from 1972 galvalum achieved more than 7 mln t; annual production of galvalum equals at present 1.5 mln t / year and had

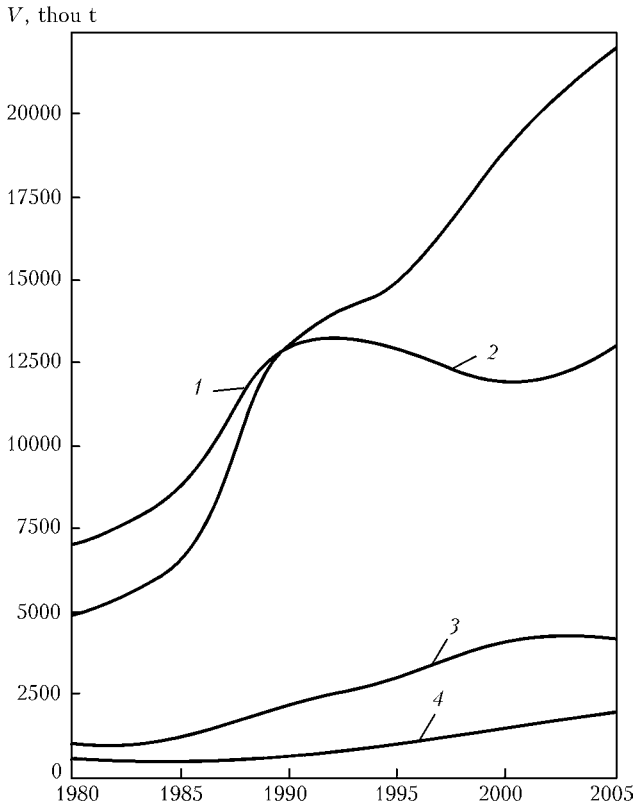

Figure 3. Growth of rolled galvanized sheet production in developed and developing countries

to double by 1989. About 300 thou t of galvalum was produced in Western Europe in 1986. It was assumed that in 2005 it would constitute 950 thou t. For production of the galvalum strip 22 licenses were sold, developer of which is the «Bethlehem International Engineering Corp.», USA [11].

Pilot production of strip with galfan coating on hot-galvanization unit was carried out in France in 1981. Information about this was not discovered. In 1985 volume of its production constituted more than 60 thou t. It was assumed that in Japan by 2005 production of steel with galfan coating could achieve 20 % of hot-galvanized steel production. By 1987, 32 licenses were sold for production of strip, wire and pipes with galfan coating [12]. Cost of the license for production of strip with galfan coating in 1981 was 50 thou USD for first unit, 40 thou USD for second and 30 thou USD for each subsequent unit. Developer of the coating was International Lead and Zinc Research Organization (ILZRO) [13].

Production of strip with lavegal coating (30 % Al) started in 1985 in Italy at a new combined unit for hot-aluminizing and application of the lavegal coatings of 140 thou t / year productivity of the «Nuova Italsider» company [14]. The product was developed by a group of metallurgical companies with participation of the Metallurgical scientific-research center. In 2005 demand for this product in Italy constituted 170 thou t.

There is no sufficient statistical data about production of rolled electrolytically coated by zinc and its alloys metal. In the USA production of the electrolytically galvanized rolled sheet constituted in 1982 490 thou t, in 1983 ---- 610 thou t, and in 1984 ---- more than 700 thou t [15]. In connection with simultaneous commissioning of big number of new highly productive electrolytic galvanization units in 2003, production of this kind of rolled sheet with the coating had to sharply increase. In FRG volume of production of the electrolytically galvanized rolled sheet constituted in 1981 190 thou t, in 1982 ---- 230 thou t, and in 1983 ---- 300 thou t [16]. According to statement of specialists of Japanese company «Nisshin Steel», production of the electrolytically galvanized rolled sheet constituted in January–November 1987 3 mln t (hot-galvanized sheet ---- 4.59 mln t), and rates of growth, in comparison with previous period in 1986, were the highest (19.5 % in comparison with 11.2 % for the hot-galvanized one). Judging from commissioning of big amount of new capacities for electrolytic galvanizing of steel strip, rates of growth in 2000s of electrolytically galvanized steel were high not just in Japan, but also in other industrially developed capitalist countries.

Hot-aluminized sheet steel. As it follows from mentioned above, production of the hot-aluminized sheet steel in the world constitutes more than 1 mln t. In CIS countries 137 thou t of aluminized sheet steel were produced in 1970, in 1984 ---- 308 thou t, and in 1987 ---- 405 thou t. Import of Japan in 1987 constituted 15 thou t. Production of hot-aluminized steel in Japan achieves, approximately, 500 thou t / year [4].

In 1960–1970s more than ten continuous specialized or combined units for production of hot-aluminized sheet steel were installed in the USA, Japan, Great Britain, FRG, France, CSSR, BPR and Argentine [4]. In 1980s new continuous units (all of them combined ones) were installed in Luxemburg and Italy (one in each) and were planned for putting into operation in the USA (1988) and the USSR (1989). In the USA among companies-producers of hot-aluminized sheet steel «Armco Steel» and «Inland Steel» are mentioned.

A unit was put into operation in 1972 in Middletown, which was designed for aluminizing strip of 0.4–2.5 mm thickness and up to 1525 mm width with two changeable baths for production of hot-aluminized steel of type I (Al–Si) and type II (Al) [10]. At present primary productivity of the unit has been increased from 200 to 300 thou t / year. American company «United States Steel» (present USX) switched over since 1983 to production of galvalum.

A new unit for hot galvanization (aluminizing) of 270 thou t / year productivity was installed in Follansbee by joint American-Japanese company «Willing-Nisshin». In Japan two companies produced hot-aluminized steel (of type I) ---- «Nippon Steel Co.» and «Nisshin Steel» (the latter one supplies 79 % of this product).

The «Nisshin Steel» company used two units (they are installed at the «Hanshin» plant in Sakai) ---- combined ones for hot galvanization and aluminizing of 164 thou t / year productivity [4]. The company informed about development of technology for one-side hot aluminizing with application of masking coating on other side of the strip, which is roasted in the annealing furnace and then cleaned off by a brush [17].

Unit of the «Nippon Steel Co.» (Japan) of 60 thou t / year capacity, installed at the plant in Yawata, is also a combined one for hot galvanization / aluminizing. In Germany the only producer of hot-aluminized sheet steel was the «Tissen Stahl» company, which produced it on the combined galvanization / aluminizing unit.

In France at plant of the «Ziegler» company in Muson a continuous double designation unit of 120 thou t / year productivity was installed for processing of a strip of 0.5–2.0 mm thickness and up to 1500 mm width.

In Italy a combined unit for hot aluminizing / production of a strip with lavegal coating of 140 thou t / year productivity was put into operation. Need in hot-aluminized steel in Italy in 1990 was estimated at the level of 50 thou t.

In1982 at the «Galvalenge» plant in Dudelenge, Belgium, unit for hot aluminizing / production of galvalum (the company name is aluzink) was put into operation for processing of a strip of 0.3–1.75 mm

thickness and 700–1500 mm width with speed of movement up to 140 m / min. Its maximal productivity was 35 t / h.

In Great Britain the only producer of hot-aluminized sheet steel became the only non-metallurgical company «Coated Metals». It produced 45 thou t of the product.

As a whole, production of the hot-aluminized steel is less adaptable to streamlined production than production of the hot-galvanized steel. It requires for higher temperatures of the melt heating (660–680 °C), which can stand only ceramic bathes. Characteristic feature for state-of-the-art units, designated for both hot aluminizing and hot galvanization, is application of non-oxidizing heating in annealing furnaces with utilization of the waste gas heat, application of air knives for regulation of the coating thickness, straightening-stretching machines, and temper mills. For additional chemical treatment of a strip with coating the chromate treatment may be used. The issue of prevention of thick layer of iron-aluminium alloy formation is successfully solved by increase of the strip movement speed.

Hot-aluminized steel of type I (Al–8–12 % Si) is characterized by improved deformability, high heat resistance, and heat-reflecting capacity. Silicon in the melt suppresses growth of iron-aluminium alloy. Investigations, carried out in Japan and other countries, showed high resistance of this steel against atmospheric action in comparison with galvanized steel.

Lead-plated sheet steel. According to the assessment made in 1982, more than 600 thou t / year of lead-plated steel were produced in the world on continuous or sheet lead-plating units or using electrolytic method [6]. Continuous hot lead plating units were installed in the USA (three), Great Britain and France (two in each), Japan, FRG, Australia, Belgium and the USSR (one in each). The most state-of-the-art and productive in 1982 was the unit for continuous lead plating, installed in Japan at plant of the «Nippon Steel Co.» in Yawata instead of the old continuous unit, productivity of which was 81 thou t / year. Productivity of the new unit is 210 thou t / year. Strips of 0.4–2.3 mm thickness and 610–1230 mm width in coils of up to 22 t mass were processes on it at strip movement speed up to 70 m / min (the highest speed for hot lead plating units). Nominal mass of the two-side coating is 75–150 g / m^2. Technology of the nickel sublayer application in amount of 1 g per 1 m^2 by electrolytic method was used for the first time on this unit. As a result a difficult for the hot lead plating units task of ensuring quality adhesion of a coating from the Pb–Sn melt to steel base was solved, it became possible to reduce content of stannum in the alloy from 15 to 8 %, more uniform fine crystalline structure of the alloy with minimal amount of pinholes was achieved, and duration of etching was reduced from 45 to 3–5 s.

Corrosion resistance of the lead plated according to the new technology sheet steel is by 25 % higher than of the steel plated according to conventional technology. Other peculiarities of the unit consist in application of air knives and, in some cases, of chemical treatment. Technology of nickel sublayer application was introduced by two American companies, which produced lead-plated sheet steel ---- «Armco Steel» at the plant in Middletown and «United States Steel» at the plant in Pittsburg. Maximal width of the lead-plated sheet steel, produced at the continuous unit in Middletown, was 1245 mm [18].

A continuous unit for electrolytic galvanization / lead plating (installed in 1972, retrofitted into the double-purpose one in 1978) operates at plant of the «Estel Ziegerlandwerke» company in Dortmund, FRG. It is designed for production of one- and two-side lead plating of sheet steel with Pb–7 % Sn coating of 2.5 and 5.0 μm thickness (5.0 μm correspond to the coating of 38 g per 1 m^2). The product may be supplied in sheets of up to 5000 mm length and strips with minimal width 20 mm; its quality does not differ from that of the hot lead plated product [6]. Old unit for electrolytic galvanization was reequipped into the unit for electrolytic lead plating at the plant in Fukuyama by the «Nippon Kokan» company, Japan. Volume of production of the lead-plated sheet steel was 24–36 thou t / year.

Lead-plated steel rolled stock is produced from mild non-alloyed cold-rolled steel, characterized by good stamping capacity. Coating in stamping is characterized by the lubrication effect. Lead-plated sheet steel has high corrosion resistance against action of petrol, diesel fuel, and salt spread over the roads. The sheets are subjected to soldering and brazing, spot and seam welding, and then they are painted. Main designation of the lead-plated sheet rolled stock is its application in fuel tanks of automobiles and in manufacturing of the radiator frames and filter parts, housings of gas meters, oil bathes, housings of condensers and other purposes.

New in technology of hot lead plating is application as a basis of a strip from the corrosion-resistant steel. For the first time production of the new product of construction designation was mastered by the «Strip Tinning» company, Great Britain. Strip of 0.25–3.00 mm thickness and 700 mm width from steels 304 and 306 was produced (application of other corrosion-resistant steels is possible) with two-side coating by lead-stannum alloy (20 % Sn–80 % Pb).

Rolled sheet with organic coatings. World production of steel rolled sheet with organic coatings in 1984 equaled 6 mln t or 1.2 bln m^2, share of North America in which constituted 47, Western Europe ---- 26, Japan ---- 22, and the rest countries ---- 5 %. Comparison with other data [19] showed that share of countries of Western Europe is by several percent less, while that of the North America countries is respectively higher. Consumption of the sheet rolled stock per capita in 1984 constituted: in Western Europe ---- 4, FRG ---- 5, North America and Japan ---- almost 10, Austria with New Zealand ---- approxi-

mately 13 kg [20]. Assumed world production of rolled aluminium sheet with organic coatings had to constitute 1.85 bln t in 2003.

In the North America countries (the USA, Canada and Mexico) the biggest dispatches of rolled sheet (steel and aluminium one) with organic coatings were in 1984 ---- 3.63 mln t. In 1985 they constituted 3.56, and in 1986 ---- 3.46 mln t (reduction of the dispatches was mainly caused by reduction of zincrometal consumption) [21]. Share of Canada and Mexico constituted 8–10 % of the dispatches. In 1996 among general amount of dispatched rolled sheet 2.82 mln t constituted steel rolled sheet and 0.64 mln t ---- aluminium one [22].

In the Western Europe countries 1.8 mln t of rolled sheet with organic coatings were produced in 2000. In FRG volume of its production constituted 837 thou t in 2000; at average 0.7 mm thickness of the strip it corresponds to application of coating on the area of 180 mln m^2 (area of one side of a strip is taken into account). For this purpose about 9000 t of coatings, applied in molten state, were used, including coatings for sheet steel of zincrometal type and coatings of back side of the strip.

In Japan, proceeding from the generalized data, volume of production of steel rolled sheet with organic coatings constituted 2.34 mln t in 2002. Volume of dispatches of preliminarily painted galvanized sheet achieved 1965 thou t in 1999. Aluminium was not widely used as a base in Japan because of high cost of electric energy [23].

As of 2002, the highest rates of increment of production of the rolled sheet with organic coatings were in Japan. This country became almost as big producer in this field as the USA.

Tasks of the metal product finish treatment development in ferrous metallurgy of Ukraine. The most important task of metallurgy of Ukraine is increase of high-tech character of the produced product and its competitiveness on the metal product market, and main directions are increased quality of the metal products, expansion of the technological process in the course of further processing of this product, and preparation of the latter for its use by the consumers.

For this purpose it is necessary to fulfill the following measures:

- develop and use scheme of development of new kinds of the products jointly with metallurgists and consumers;
- expand assortment of the metallurgical products;
- widely use technology of heat and heat deformation treatment of the metal from the rolling heating;
- establish a number of interbranch centers for heat treatment of metal products (such centers were established within last 15–20 years and successfully function in industrially developed countries);
- significantly increase production of rolled sheet from carbon steels with protection coatings;
- organize in big research centers laboratories for carrying out standard and special tests of rolled stock with coatings.

High quality of the products, produced on the units for hot galvanization and application of electrolytic, organic and other coatings, enables expansion of the field of their use. Rolled sheet with coating is corrosion-resistant. In many cases it may be used as a decorative facing and roofing material, it has special properties and is subject to cold forming to shape and has a number of other designations. Absence of corrosion of the steel is guaranteed for the period of 5–40 years.

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