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Aluminum gas-thermal coatings allow to reduce metal and heat losses during hot rolling

At the present time in Russia and abroad some experience in the application of gas-thermal coatings (GTC) have been accumulated to improve the metallurgical industry [1, 2]. The chair of Technology and Equipment of Tube Production (TOTP) of the National Research Technological University "Moscow Institute of Steel and Alloys" (NITU "MISIS") investigated the effectiveness of GTC in hot rolling. Considered method of applying GTC using electric arc metallization is the most simple and efficient [3]. The authors have studied possibility of using aluminum to enhance GTC for hot-rolled steel, copper and titanium pieces: reduction of metal loss with the fumes, dross and trimmings, reduction of heat loss peal. Following results were obtained.

1. Reducing the loss of metal. High-temperature gas corrosion that occurs during heating of blanks in the furnace atmosphere containing oxygen, prior to hot rolling, impedes production of rolled products. Scaling leads to metal loss, promotes autopsy of subcortical bubbles, increases the size of surface defects of casting of origin, accompanied by decarbonization and gas saturation. As a result, formation of a thick layer of rolled-in scale in the rolling process increases labor costs in cleaning of finished steel, and reduces its quality.

Aluminum GTC, containing in its composition and aluminum oxides forming during its heating with metal base diffusion layer containing a heat-resistant intermetallic compounds is a promising heat-resistant coating. Since rolling of the heated billet is a significant increase in the area of the rolled sheet, then, as experience shows, there is a proportional decrease in the diffusion layer thickness up to his disappearance at the box office. Heating of steel billets was investigated within a temperature of 1020–1280 ^{o}C prior to rolling. The thickness of the GTC ranged 100–400 mcm. Following results were obtained.

At Oskol Electric Steel Works, when using the billets with section 300×360 mm of steel SKh-15, 1 kg of aluminum GTC reduces losses and wastes in the scale by about 14 kg. At the same time on the surface of the finishing profile with a diameter of 122 mm there was no carbon-free layer. This has important implications for long products of tool steel, the production is in accordance with State standards stipulated thickness decarbonized layer.

At «Elektrostal» metallurgical works, aluminum GTC was applied to varietal billets of 90 mm diameter from steel R6M5 after heating and rolled to small sections at the 350/250 bar mill to the bars with 20 mm diameter. When using GTC, no metal is lost in scale, there was no carbon-free layer and the surface of the bar had high purity without pitting of the scale. It does not capture conditions that have worsened the problems in the billets during rolling in the stands.

In the section rolling shop of «Severstal» metallurgical works, aluminum GTC with 150 mcm thickness is applied to varietal brand of billets with section 100×100 mm from 20G2R steel, obtained by rolling on the 350 section mill from continuously cast billets with section 150×150 mm and stripped on the machines «Heinrich Rau». Coated and uncoated workpieces are heated in a furnace of 150 mill and rolled to a round profile with a diameter of 6.5 mm. The temperature in the welding zone of the furnace was 1200 ^{o}C, soaking was occurred in the area 1280 ^{o}C. The actual heating time for billets was 1 hour and 43 min.

Analysis of the magnitude of decarbonized layer on the samples from the coated and uncoated billets after heating in a furnace of 150 mill has shown the level of the value of decarbonized layer: 0.40 and 0.32 mm for the workpieces without and with coverage respectively. The pattern of distribution of decarbonized layer preforms for advanced state identically. Decarburization in the finished rolled products obtained from uncoated stock is by 0.3–0.4 % higher than the workpiece surface, where the average value of this layer was in the range 0.6 – 0.8 %, in line with regulatory requirements, whereas this parameter for the uncoated samples had average decarbonized layer 1.1 – 1.2 %.

The 2800 mill at "Severstal" metallurgical works has examined the effect of GTC aluminum deposited on the slab after high-quality abrasive cleaning of the surface of hot rolled sheets. The coating was applied using EM-12 metallizer at the top and bottom of wide slab with thickness 150–250 mm from steel 15HSND, AB2-1, 09KhN2MD, 17G1S and AK, and only the top - from steel Gr65. Slabs were heated in the furnaces and rolled to a thickness of 16–45 mm. Further rumblings after 48 h were subjected to heat treatment in a roller oven. It was found out that deposition of aluminum slabs reduces waste and scaling, eliminates or reduces the depth of decarbonized layer and cracks on the surface of the sheet. Metal loss on waste and dross on coated slabs were 2.1–7.8 kg/t that is less than that for slabs without coating, having lower usage ratios from 1.195 to 1.152.

Decreased thickness of the defect layer on the surface of sheet metal is especially important for continuously cast steel sheets. The sheets of steel with applied coatings of 09KhN2MD steel showed no signs of decarburization and their scale thickness was less by 7–8 times than that at the surface of the comparative sample of uncoated sheets. This diffraction phase analysis showed presence of a dense protective coating on the sheet surface, which inhibits oxidation of steel, suppressing the formation of higher iron oxide – hematite, and has high hardness and high resistance to remove it from the surface.

Preparation of sheets with a high surface quality was associated with the choice of the thickness of the coatings deposited on slabs. It was found out that for this purpose, the thickness of the sprayed coating (h_C) for steels 15KhSND, 09KhN2MD, Gr65 has the thickness of 0.58-0.83, providing effective protection against metal fumes and slag ($h_{C\ EF.}$). For steels Gr65, 17G1S, relation h_C / $h_{C\ EF.}$ was 0.43–0.52, and for steel 12KhN3MD – 0.33–0.35. For all slabs of sputtered metal, mass loss reduction in waste and dross was 20–26%. As a result, the etching patterns for mass scale samples coated after rolling and heat treatment was less than for samples without coating, which was confirmed by the results of metallographic analysis.

Depth of decarbonized layer applied on uncoated steel occurred 0.18 mm, which was confirmed by the values of microhardness. As a result of X-ray phase analysis for steels with h_C / $h_{C\ EF.}$ = 0.58–0.83, high levels of intermetallic $FeAl_3$ were noted in the surface layer. However, the aluminum coating inhibits oxidation of steel, suppressing formation of hematite. On the surface of steel sheet with relationship h_C / $h_{C\ EF.}$ = 0.43–0.52 after heat treatment, intermetallic Fe–Al were found. Deposition of aluminum helped to preserve the easily removed wustite FeO and decrease resistance for removing magnetite Fe_3O_4 in the scale. It should be noted that deposition of coatings with h_C / $h_{C\ EF.}$ ~ 0,4 provides high-quality sheet surface after normalization, and that with h_C / $h_{C\ EF.}$ ~ 0,5 provides high-quality sheet surface after quenching and tempering. At the same time a sufficient reduction of mass loss of the metal via carbon monoxide and scaling was achieved.

It is known that in the process of production of heavy plates in hot rolling mills there is a problem of uneven temperatures along the length and width of the rolled sheet, which negatively affects on the mechanical properties and quality of finished products [4,5]. In [6] it is showed that thermal and electrical conductivity of the diffusion layer formed on the surface of the slab decrease after its heating with deposition of aluminum coating, and emissivity coating is 0.4-0.45 at 850 - 1150 ^{o}C [7].

Therefore, in order to reduce non-uniformity of temperature along the length and width of the rolled sheet in hot rolling stands, and thus to eliminate the lateral cracks and alignment on the mechanical properties of finished rolled products, and thereby to reduce the side and end trim, aluminum GTC in the form of stripes on the edges of the adjacent large and the narrow edge of the slab is applied. Aluminum gas-thermal coatings sprayed on thick slabs of 315 mm of steel 10G2FB-U in the form of strips along the edges of adjacent wide and narrow faces, or just on the perimeter of broad sides. Slabs are rolled on the hot rolling mill 5000 of «Severstal» metallurgical works for the final sheet thickness 21.2 mm and width up to 320 mm. In the case of spray coating only on the broad side of the slab perimeter, it covers band located up to 80 mm from the lateral edge. From the side of the front and rear ends of steel sheet, coating was presented up to 1500 mm.

It is established that temperature drops and the width of peals (thunder at a distance of 500 mm from the edge), obtained from the slab is coated at 25 ^{o}C, while production temperature ranged - 36–53 ^{o}C. However, this was not enough to completely avoid the appearance of cracks on the finished product. The lateral cracks are received from the slab with a coating formed in the absence of site coating after rolling, since rolling is a shift coating, and the wide side of the rolled sheet metal is not coated. Samples after etching are subjected to macroscopic analysis for cracks detection and to tensile test for determining the mechanical properties of the finished products received from the slab with and without the application of a coating. These samples are taken from the head and end of rolled stock at a distance of 900–1200 mm from its edge.

It is noted that on the surface of samples with coating and without coating, the heterogeneous scale layer was observed along sample thickness. However, the surface of steel and aluminum with etched area differed from the base metal, which was characterized by the presence of elements of Fe-Al diffusion layer. According to the specifications adopted by the plant, the mechanical properties were investigated to satisfy the following values: yield strength σ_T = 500-590 MPa, tensile strength σ_B = 590-690 MPa, σ_T/σ_B = 0.92, elongation $\delta \geq 22$ %. Analysis of the mechanical properties of the samples taken at a distance of 220-860 mm from the front end and from the edge of the rolled metal that had been produced from the slab with coating and without coating, showed the following regularities. If we shall consider initial slabs with σ_B and σ_T/σ_B satisfying the requirements of specifications, then σ_T and δ do not meet the requirements of specifications only at the distance of 380 mm from the edge. In the case of rolling of sheet metal from uncoated slabs, σ_B and σ_T/σ_B don't satisfy the requirements of specifications at the distance of 220 mm from the edge, while σ_T - at the distance of 380 mm from the edge, and δ - 780 mm from the edge, which increases the trimmings.

It is known that copper is well formed in hot and cold conditions and can be deformed without annealing up to 95–97 % [8]. However, during hot rolling of copper at the temperature up to 900 °C, there is intense scaling that leads to great losses of the metal. Deposition of aluminum coating by electric plating on copper billet and its subsequent heating and hot rolling allows to produce Cu-Al diffusion layer on its surface having hardness, heat resistance and wear resistance several times greater than copper. Therefore, this method of coating is used in the work to protect the copper from scaling during hot rolling of sheet metal.

Wire of AD1 (h_C) has coating thickness 150 mcm and 300 mcm, this coating is applied by metallizer EM-14M on samples of copper M1. The samples were incubated with coated electric resistance furnace in air atmosphere SNOL at 880–900 ^{o}C during 1 hr and then subjected to hot rolling on the laboratory mill 150. One sample with different thickness was subjected to be applied with deposited coating. The remaining samples were placed in the oven again and held there until reaching the temperature of 880–900 ^{o}C, after which the samples were subjected to further rolling. Recent samples were rolled in 11 passes to a thickness of 1.57 mm with a total reduction of 91 %.

Visually, it was found that the samples coated with yellow after heating contained the diffusion layer adjacent to the copper, aluminum layer and the oxidized surface layer. After heating of the samples, aluminum appeared in the surface layer, and aluminium had a silver color and flowed during rolling. At the same time, the thicker was the coating, the thicker was the remaining layer of aluminum. The oxidized surface layer is less ductile than the diffusion layer, so it is cracking during rolling with fragmentation. After fragmentation of the oxidized layer and the diffusion layer it deformed plastically simultaneously with copper base. The metal with this oxidized layer is rolled up to the minimum thickness to h_C = 150 mcm when it is almost not visible on the image. Cu-Al diffusion layer remained solid on the surface of the copper before the end of rolling.

During the study of samples with 91 % reduction, fragments of the oxidized layer were found on the surface. Then the Cu-Al diffusion layer was located in the absence of fragments that left the surface of the sample. Between the Cu-Al diffusion layer and the copper there is a transition layer. According to the results of metallographic and x-ray studies, we can suggest that fragments of the oxidized layer with thickness of 80 mcm consist mainly of spinel, which is a mixture of oxides of copper and aluminum, and have microhardness 360–380 kg/mm^2. Thickness of Cu-Al diffusion layer is 50–100 mcm and consists of β-phase on the basis of the connection between Cu_3Al and α-phase making a solid solution of aluminum in copper, and has microhardness 350–400 kg/mm^2. The transition layer has thickness of 5–20 mcm and consists of α-phase making a solid solution of aluminum in copper, and has a microhardness 340–360 kg/mm^2. The copper base has a microhardness 110–140 kg/mm^2.

2. Reduction of heat loss in rolling. During hot rolling of billets of PT-3V titanium alloy with aluminum GTC [4] in rolls with a built-in thermocouple, it was found out that GTC reduced surface temperature of the rolls in the deformation to 200–300 ^{o}C. This is explained by the fact that the GTC when heated turns into aluminum oxide and intermetallic compounds, which have low thermal conductivity. It is shown that the efficiency of coating increases by almost 2 times for pre-compacting pressure in the range 3-12MPa [4, 9]. This is a consequence of reducing roughness and porosity of the GTC.

To keep warm in the rolled sheet, hot rolling mills should use heat screens. Reflective screens (RS) are applying as reflective layer of compacted aluminum, effectively using GTC, which combines high reflective properties with high heat resistance [10-12]. Screens with this coating have been successfully tested in the intermediate roller table at 1700/2800 hot rolling mill of "Severstal" metallurgical works and 2000 hot rolling mill of Novolipetsky metallurgical works (NLMK) [10]. The optimum thickness of the coating for the reflective surface RS is selected from the conditions and should provide good corrosion-resistant properties with sufficient adhesion strength of coating with the carrier substrate. Basically, the coating thickness does not exceed 250 mcm. Additional compaction was carried out at the rolling mill, the right car cover provides reduction up to 50 %. Good self cleaning surfaces also showed GTC with sandpaper. Evaluation of efficiency of the screen with an aluminum coating is provided by measuring the surface temperature of the peals during their cooling below the screen and without screen. It was established that the temperature of the rolled sheet under the screen was higher by 80–120 ^{o}C, compared with that of the rolled sheet with cooling without a screen.

Screens with GTC at 1700/2800 hot rolling mill of "Severstal" metallurgical works has been successfully exploited for more than 7 months without replacement. During this period, their reflective properties have not changed, as can be judged by the constancy of heating temperature during the passage of RS rolled sheet under these conditions. When installing RS with an aluminum bat in front of GTC scissors at 2000 mill of Novolipetsky metallurgical works (NLMK), screens were lowered to a height of 250 mm above the roller table. Significant deterioration in their reflective properties in the first three months have been showed because of impact of falling scale, process water, cooling rollers and steam. If you disable individual sections of the cooling rollers, reflective properties of the screen in these stressful working conditions persisted for over a month at their warm-up to 520–570 ^{o}C.

Conclusions

1. Metal loss on waste and dross on slabs of low-alloy steel with an aluminum GTC applied by electric plating, were 2.1–7.8 kg/t. It is less than that for slabs without coating. Expense ratio decreased from 1.195 to 1.152.

2. On steel billets obtained from hot-rolled steel, varietal, coated, carbon-free layer was absent or its thickness was less than that without coating.

3. Aluminum GTC applied to the surface of the slab of low-alloy steel is an effective material for reducing thickness of the rolled-in scale (up to 5 times) and the depth and number of surface cracks on the sheets. The coating on strips along the edges of adjacent wide and narrow sides eliminates appearance of cracks on the surface of overcooled edge zones of plates and align the mechanical properties along their length.

4. Application of aluminum coating thickness of 150 mcm by electric plating on copper billets is an effective method of protection against fumes and scaling during heating to 900 ^{o}C and subsequent hot rolling. In the process of hot rolling, Cu-Al diffusion layer is not destroyed and deformed with the substrate.

5. Pre-compaction is caused by hot rolling of billet with aluminum GTC before heating and increases its protective properties.

6. Application of GTC on the aluminum billet of titanium alloy PT-3V reduces heat transfer from the surface of rolls during hot rolling.

7. Application of reflective screens, in which compacted aluminum GTC was used as reflective layer in the area of intermediate rolling group of hot rolling mills showed their high efficiency to keep rolled sheet warm.

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