EFFECT OF DUCTILE SUB-LAYER ON HEAT RESISTANCE OF MULTILAYER DEPOSITED METAL

I.A. RYABTSEV, A.A. BABINETS and **I.I. RYABTSEV**
E.O. Paton Electric Welding Institute, NASU, Kiev, Ukraine

Effect of deposition of a ductile sub-layer on heat resistance of deposited metal 25Kh5FMS was studied. It was established that deposition of the ductile sub-layer with wire Sv-08A provides an approximately 20 % increase in heat resistance of the 40Kh steel specimens deposited with flux-cored wire PP-Np-25Kh5FMS.

Keywords: *arc cladding, deposited metal, multilayer cladding, ductile sub-layer, heat resistance*

Thermal fatigue is a characteristic type of damage of the tools used for hot deformation of metals, such as forming rolls, hot shaping dies, hot cutting knives, and many others that are subjected to the effect of thermal cycling [1, 2].

Thermal fatigue cracks initiate on the surfaces of such tools after a certain quantity of thermal cycles. The process of their formation depends on the properties of tool materials and a number of parameters that characterise service conditions. Even before initiation of cracks the material experiences irreversible structural changes, which may affect its mechanical properties, shape and size of parts [3–10]. Normally, the quantity of heating–cooling cycles to formation of the fire crack network serves as a characteristic of resistance of materials to thermal fatigue.

Surface layers of a forming roll (die) heat up in contact with a billet whose temperature amounts to 1200 °C, and dramatically cool down after this contact is terminated. Hence, each heating–cooling cycle will cause a change in volume and stress-strain state of these layers (Figure 1).

Surface layers expand in heating, but colder internal layers prevent it, this causing elastic compression

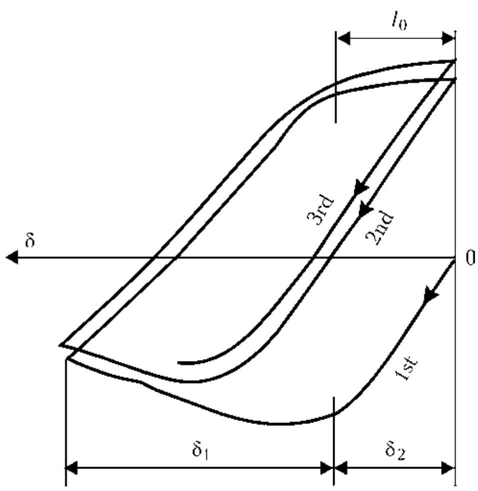

Figure 1. Residual plastic δ_1 and elastic δ_2 strains causing thermal fatigue [8]: 1–3 — hating-cooling cycles; l_0 — elongation

of the external layers. If a temperature gradient from the surface deep into a part is high, the values of compressive stresses may amount to the yield stress value. In rapid cooling the surface layer will gradually compress, but because of resistance of the more heated internal layers this process will be hampered or will not take place at all, and the surface layer will first elastically and then plastically expand. Upon returning to the initial temperature the size of the surface layer will coincide with its initial size. However, the values of residual tensile stresses in it may amount to the yield stress value.

The depth of the plastically deformed layer is determined by heating and cooling conditions, as well as by physical-mechanical properties of material of this layer, such as thermal expansion coefficient, elasticity modulus and thermal conductivity. Structural changes in the material during thermal cycling, and strengthening and weakening in particular, at different stages of cyclic deformation may cause a change in type of the hysteresis loop. If reaching the maximal cycle temperature is followed by holding till the next cooling cycle, this will cause relaxation of thermal stresses and, as a result, change in the hysteresis loop (see Figure 1). All this indicates that there is no such a stress value which can characterise thermal fatigue [4].

Repeated plastic strains, like under conditional cyclic loading, lead to formation of cracks, and simultaneously with their deepening and extension a fire crack network forms on the surface.

The purpose of this study was to investigate the effect of a sub-layer, geometric sizes of the sub-layer and a wear-resistant layer on heat resistance of the clad parts.

Investigations were carried out on steel rolls designed for hot rolling. As mentioned above, thermal fatigue of the tools used for hot deformation of metal is affected by the maximal heating temperature in a zone of contact of a tool with a heated billet, as well as by the distribution of temperature in its surface layers.

The character of distribution of temperature across a roll during rolling was determined by the calculation-experimental method at the first stage of the in-

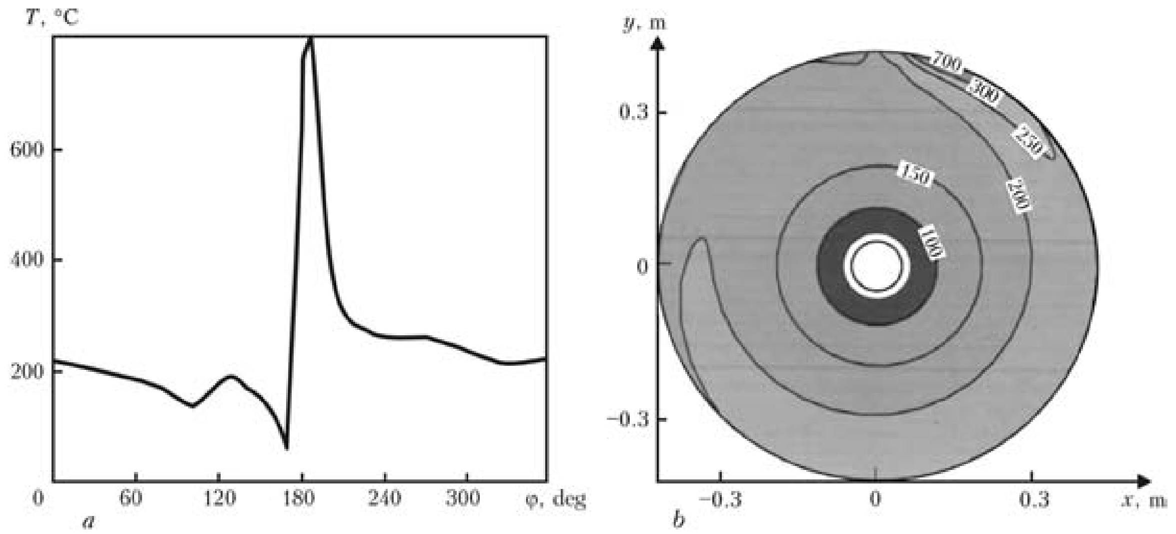

Figure 2. Distribution of temperature on the roll surface (*a*) and calculated isothermal lines of temperature fields across the roll section (*b*) during rolling

vestigations [11]. It is reported [1, 2] that in contact with the deformed billet the surface layers of the roll heat up to a maximal temperature of 700–800 °C (Figure 2, *a*). Then, during rotation of the roll, they intensively cool down, and their temperature dramatically decreases to 200 °C. The temperature at the roll centre is 20 °C (Figure 2, *b*).

As follows from these data, in operation of a forming roll the thermal cycle is of a serrated character, and holding at the maximal temperature is absent. In this connection, in calculation of the thermal fatigue it is possible to ignore the creep, which substantially decreases resistance to the thermal fatigue [3]. Thickness of the layer heated to 700 °C is 4–6 mm, and temperature of the underlying layers dramatically decreases to 300–400 °C (total thickness of the layers heated above 300 °C is 6–8 mm) and then to 200 °C.

Therefore, thickness of the working layer of the forming roll subjected to cyclic thermal loads will be 6–8 mm. A more important characteristic for materials of the layers heated below 200 °C will be fatigue strength under cyclic service force loading. So, it is a ductile sub-layer that should play an essential role in this case, as fatigue strength of the base metal of the forming roll (as a rule, these are medium- and high-carbon low-alloy steels) is low.

Geometric sizes of the sub-layer and main layer were selected on the basis of the above calculations on specimens for testing of heat resistance of the metal deposited with flux-cored wire PP-Np-25Kh5FMS, which is widely used for cladding of forming rolls, dies and other similar parts.

Cladding by the following methods was performed on billets of steel 40Kh: cladding with flux-cored wire

Table 1. Characteristics of deposited layers on experimental specimens

Specimen No.	Type of alloying of deposited metal	Quantity of deposited layers	Thickness of wear-resistant layer after grinding, mm	Hardness of deposited metal *HRC*
1.1	25Kh5FMS (without sub-layer)	2	3–4	45–47
1.2		4	7–8	46–47
1.3	Sv-08 + 25Kh5FMS sub-layer	2 + 2	3–4	43–45
1.4		2 + 4	7–8	44–46

Table 2. Results of layer-by-layer chemical analysis and hardness of deposited metal of the 25Kh5FMS type

Layer No.	Content of alloying elements, wt.%						*HRC*
	C	Si	Mn	Cr	V	Mo	
1	0.22	0.69	0.53	4.5	0.25	0.87	46–48
2	0.24	0.74	0.56	5.4	0.37	0.95	48–50
3	0.26	0.79	0.64	5.5	0.40	1.01	49–51
4	0.26	0.76	0.64	5.4	0.40	0.99	49–51
25Kh5FMS (TUU 05416923.024–97)	0.22–0.33	0.7–1.2	0.4–1.0	4.7–5.9	0.3–0.6	0.9–1.5	45–53

Table 3. Heat resistance of deposited metal specimens

Specimen No.	Quantity of heating–cooling cycles		
	To initiation of first cracks	To propagation of cracks	To formation of crack network
1.1	69	114	175
1.2	66	104	170
1.3	72	123	186
1.4	86	130	200

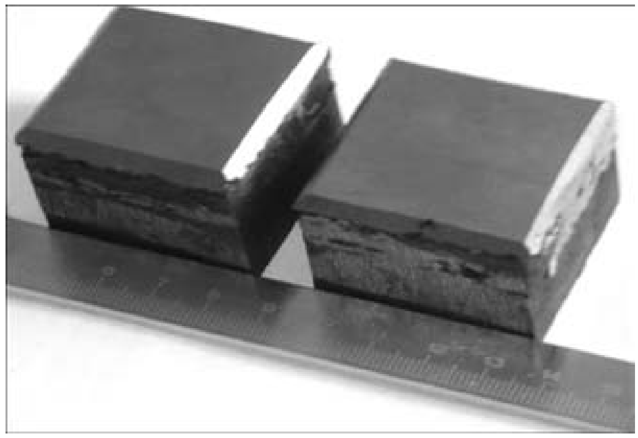

Figure 3. Appearances of clad specimens

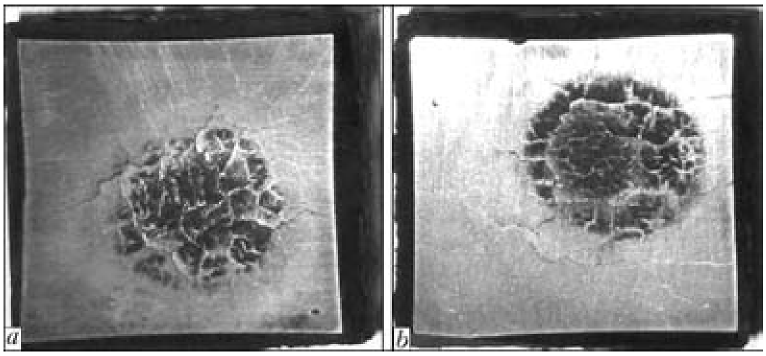

Figure 4. Appearances of the specimens clad with flux-cored wire PP-Np-25Kh5FMS without (*a*) and with sub-layer Sv-08 (*b*) after heat resistance tests

PP-Np-25Kh5FMS without a sub-layer (in two and four layers, total thickness of the deposited metal after grinding was 4 and 8 mm, respectively); deposition of the ductile sub-layer with wire Sv-08 (in two layers) and wear-resistant layers with flux-cored wire PP-Np-25Kh5FMS (in two and four layers, total thickness of the wear-resistant deposited metal after grinding being 4 and 8 mm, respectively) (Table 1).

Cladding was performed with overlapping of beads approximately to 50 % by using 2.8 mm diameter wire under the following conditions: cladding current I_c = = 350–400 A, arc voltage U_a = 28–30 V, and cladding speed v_c = 16 m/h. After cladding the specimens were slowly cooled under a flux layer.

Layer-by-layer chemical analysis of the deposited metal, as well as standard composition of the metal deposited by using flux-cored wire PP-Np-25Kh5FMS are given in Table 2. As seen from the Table, the deposited metal corresponding in chemical composition to specification TUU 05416923.024–97 is provided already in the second layer.

Then specimens measuring 40 × 40 × 30 mm for heat resistance tests were cut out from the clad billets. The clad surface of the specimens with plane sizes of 40 × 40 mm was subjected to grinding prior to the tests (Figure 3). Three-four specimens of each cladding variant were made and tested.

Heat resistance was studied by using a modular machine developed by the E.O. Paton Electric Welding Institute for testing different properties of the deposited metal [12].

Testing conditions were as follows: heating of the ground deposited surface of a specimen to 800 °C was provided by using a gas cutter (heating spot of 15 mm, plane size of the heated surface of a specimen of 40 × × 40 mm), and cooling of the heated surface with a water jet to 60 °C. The heating–cooling cycles were repeated to formation of a fire crack network, which can be seen with the unaided eye. Heat resistance was evaluated on the basis of a number of the heating–cooling cycles to initiation of the first cracks and reaching of a certain degree of cracking, i.e. formation of the fire crack network.

The test results (average over 3-4 specimens of each type) are given in Table 3, and appearances of the specimens after the tests are shown in Figure 4.

As proved by the results obtained, deposition of the sub-layer provides heat resistance of the deposited metal of the 25Kh5FMS type, especially at a stage of formation of the fire crack network.

CONCLUSIONS

1. It was established by the calculation-experimental method that thickness of the working layer of a roughing stand forming roll, which is heated to 200–700 °C in the zone of contact with a billet formed, is 6–8 mm. For materials of the layers heated below 200 °C an important characteristic is fatigue strength under cyclic service force loading. On this basis, it is recommended to use low-carbon low-alloy steels characterised by high ductility and fatigue strength for cladding of a sub-layer on the hot forming rolls.

2. It was experimentally found that deposition of a ductile sub-layer with wire Sv-08A provides an approximately 20 % increase in heat resistance of the 40Kh steel specimens clad with flux-cored wire PP-Np-25Kh5FMS.

1. Frumin, I.I. (1961) *Automatic electric arc surfacing*. Kharkov: Metallurgizdat.
2. Tylkin, M.A. (1971) *Increase in service life of metallurgical equipment parts*. Moscow: Metallurgiya.
3. Dulnev, R.A., Kotov, P.I. (1980) *Thermal fatigue of metals*. Moscow: Mashinostroenie.
4. Balandin, Yu.F. (1967) *Thermal fatigue of metals in ship and power machine building*. Leningrad: Sudostroenie.
5. Davidenkov, N.N., Likhachev, V.A. (1962) *Irreversible forming of metal in cyclic heat action*. Moscow: Mashgiz.
6. Tylkin, M.A., Yalovoj, N.I., Polukhin, P.T. (1970) *Temperature and stresses in parts of metallurgical equipment*. Moscow: Vysshaya Shkola.
7. Birger, I.A., Shorr, B.F., Demianushko, I.V. et al. (1975) *Thermal strength of machine parts*. Moscow: Mashinostroenie.
8. Artinger, I. (1982) *Tool steels and their heat treatment*. Moscow: Metallurgiya.
9. Dovnar, S.A. (1975) *Thermomechanics of strengthening and fracture of forging dies*. Moscow: Mashinostroenie.
10. Troshchenko, V.T., Shemegan, Yu.M., Sinyavsky, L.P. (1974) Study of fracture mechanisms of alloys in thermal fatigue and in combined effect by cyclic mechanical and thermal stresses. In: *Proc. of All-Union Symp. on Low-Cycle Fatigue at Higher Temperatures* (Chelyabinsk), Issue 2, 137–156.
11. Ryabtsev, I.A. (2010) *Reconditioning and strengthening of parts used under wear conditions and different types of cyclic loading by the cladding methods*: Syn. of Thesis for Dr. of Techn. Sci. Degree. Kiev.
12. Ryabtsev, I.I., Chernyak, Ya.P., Osin, V.V. (2004) Modular machine for testing of deposited metal. *Svarshchik*, **1**, 18–20.

PECULIARITIES OF THERMAL SPRAYING OF COATINGS USING FLUX-CORED WIRE (Review)

B. WIELAGE, C. RUPPRECHT and **H. POKHMURSKA**

Institute of Materials Science, Chemnitz University of Technology, Germany

Methods for production and application of flux-cored electrode wires for flame and electric arc spraying of various-purpose coatings are considered. Possibilities of applying advanced 2.0 and 2.8 mm diameter flux-cored wires for electric arc deposition of coatings are noted. It is shown that high-speed filming can provide important information on the nature of running of the spraying process which determines the coating quality.

Keywords: *thermal spraying, coatings, flux-cored wires, designs of wires, coating methods*

The technology of thermal spraying has found wide commercial application, in particular, for deposition of wear- and corrosion-resistant coatings. As reported by Linde AG [1], flux-cored wire is one of the most widespread consumables for thermal spraying, its annual utilisation amounting to over 50,000 t. The use of such wires allowed not only the range of their application to be widened to electric arc, plasma and flame spraying, in contrast to solid wires, but also the properties of the resulting coatings to be changed as needed, this explaining the year to year increase in their production volume and choice.

Designs and materials of flux-cored wires. Flux-cored wire consists of a sheath made from metal strip (steel, nickel, cobalt etc.) and a core, which is a powder of one component or a mixture of powders of alloying components and hardening particles (ferroalloys, pure metals, carbides, borides etc.). The flux-cored wires come in several designs. In practice, the most common designs of the flux-cored wires are overlap butt, tight butt and tubular.

The main groups of flux-cored wires used for spraying of repair, corrosion- and wear-resistant coatings are given in the Table. The iron-, nickel-, cobalt- and aluminium-base flux-cored wires are now available in the market. The main application field of the coatings deposited by flux-cored wire spraying is protection from different kinds of wear, the most-used coatings being coatings of high alloys or coatings containing hard particles, as well as pseudo-alloys.

Another important application field of the coatings deposited by using flux-cored wires is protection from corrosion, including from gas corrosion at increased temperatures, for which the use is mainly made of nickel-base alloys.

Functional coatings, e.g. for improvement of antifriction properties of friction surfaces, are produced by spraying of flux-cored wires with solid lubricants, e.g. boron nitride, contained in their charge. Alumoceramic coatings sprayed by using tubular flux-cored wires, the charge of which consists of hard ceramic particles, have been developed lately for wear and corrosion protection of surfaces of the parts made from magnesium alloys. These coatings can also be used as anti-sliding ones.

Chemical and phase compositions of the flux-cored wire charge may vary within wide ranges, this opening up considerable opportunities for development of new systems of the coatings and, hence, for further expansion of their practical application fields [2].