DOI: http://dx.doi.org/10.15407/tpwj2018.04.02

EFFECT OF MAIN IMPURITIES ON FORMATION OF CRACKS IN WELDING OF COPPER-NICKEL ALLOYS AND SURFACING OF MONEL ON STEEL

V.A. ANOSHIN, V.M. ILYUSHENKO and **E.P. LUKYANCHENKO**
E.O. Paton Electric Welding Institute of the NAS of Ukraine
11 Kazimir Malevich Str., 03150, Kyiv, Ukraine. E-mail: office@paton.kiev.ua

Effect of main impurities on formation of cracks in welding of copper-nickel alloys, including in welding and surfacing of monel on steel, was investigated. Methods of optical metallography and electron-fractography analysis determined that the cracks have intercrystalline and solidification nature. Emission X-ray spectrum analysis determined significant (27 times) enrichment of gray surface of cracks forming in monel welding. It is shown that oxygen intensifies detrimental effect of sulfur in monel surfacing in contrast to welding of low-carbon steel. Carried theoretical calculations of significant saturation of boundaries of grains with detrimental impurities at small coefficient of distribution are of interest for explaining the reason of solidification crack formation on other nickel alloys. 6 Ref., 1 Table, 4 Figures.

Keywords: *copper-nickel alloys, detrimental impurities, solidification cracks*

Copper-nickel alloys having improved mechanical properties and high corrosion resistance are widely used in marine shipbuilding and chemical machine building for manufacture of parts operating in different aggressive media. Complexly alloyed copper-nickel alloys containing additives of such elements as aluminum, iron and manganese are very perspective. In this connection the problem of investigation of these alloys weldability is relevant.

Present work is continuation of investigations on evaluation of impurities effect on copper weldability [1], in particular, applicable to copper-nickel alloys as well as nickel-copper alloy monel.

Preliminary evaluation of weldability of pilot alloys MNZh5-1; MNAZhMts6-1.5-1; MNZhMtsA 13-1.5-3-1 was carried on procedure developed at the E.O. Paton Electric Welding Institute using LTPM or «fish skeleton» specimens [1].

Electron-fractography and metallographic analyses of crack surface showed their intercrystalline and solidification nature (Figure 1).

Figure 2 presents a crack on fused grain boundaries in near-weld zone of MNZhMtsA 13-1.5-3-1 alloy. The method of emission X-ray spectrum analysis determined that the crack surfaces have 3–5 times more detrimental impurities (lead, phosphorus, bismuth). Pilot ingots with their different content were cast to evaluate effect of these impurities on MNZh5-1 alloy weldability. The specimens for evaluation of alloys

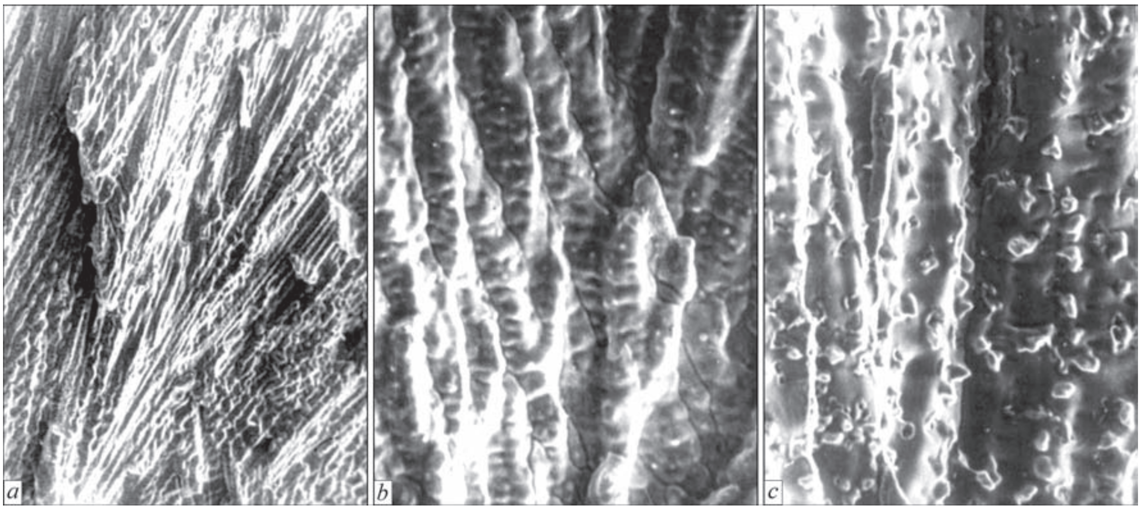

Figure 1. Intercrystalline (*a*, ×150) and solidification (*b*, ×800, *c*, ×1200) nature of cracks in monel welding

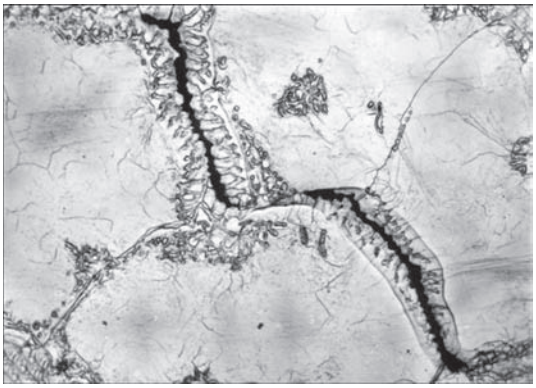

Figure 2. Crack on fused grain boundaries in near-weld zone of MNZhMtsA13-1.5-3-1 alloy

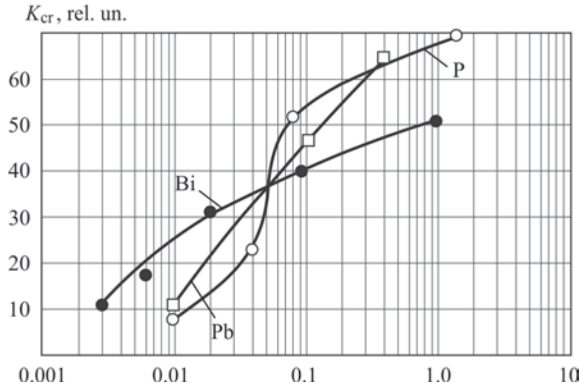

Figure 3. Dependence of index K_{cr} for alloy MNZh5-1 on bismuth, lead and phosphorus concentration in it

susceptibility to crack formation were cut out from these ingots. Figure 3 represents the dependence of K_{cr} index for pilot alloy containing different concentrations of bismuth, lead and phosphorus.

Susceptibility to crack formation in welding and surfacing of NMZhMTs28-2.5-1.5 grade monel on steel was also investigated. Welding of monel specimens was carried out in argon medium with non-consumable electrode using the procedure indicated above. Surfacing was made on low-carbon steel of 20 mm thickness under AN-26S flux using standard 3 mm diameter wire of NMZhMTs28-2.5-1.5 grade. It is determined that crack nature is the same as for copper-nickel alloys. The surface of cracks is mostly enriched with sulfur (in 27 times). Carried calculations on Smith formula[*] [2] (the results are given in the Table) also indicate significant enrichment of grain boundaries with impurities in comparison with initial concentration of C_0 (for example, sulfur with $K_o \approx 0.005$ for monel).

It should be noted that there is an increase of crack formation susceptibility in surfacing of monel on steel under oxidized flux AN-18. Therefore, the experiments were carried out on investigation of common effect of oxygen and sulfur on crack formation using V.V. Podgaetsky procedure [4]. Figure 4 shows the examination results of joint effect of oxygen and sulfur on crack formation in surfacing of monel on steel. As can be seen from obtained data, increase of oxygen content in weld reduces critical content of sulfur, at which cracks appear in the welds. At high concentrations of oxygen and small concentrations of sulfur there are microcracks, which do not propagate due to small amount of sulfur in the weld metal. Taking into account that copper and nickel at solidification temperature have more chemical affinity to sulfur than iron, appearance of sulfides Cu_2S and Ni_3S_2 in monel surfacing are more probable. They form the eutectic with melting temperature 728 °C or ternary eutectic of Ni–Cu–S system. Introduction of oxygen promotes more decrease of eutectic temperature and, apparently, rises surface activity of sulfur in contrast to low-carbon steel, where, as is known [4], oxygen reduces detrimental effect of sulfur on solidification crack formation.

Phosphorus has the same effect as sulfur. Typical intercrystalline cracks appear at more than 0.045 % phosphorus content in the weld in surfacing on steel as well as monel welding.

Relative segregation of impurities in different distance X_2 from grain boundary in depending on distribution coefficient

v_{cr}, cm/s	$C_{cr}(X_2)/C_o$											
	$K = 0.1$			$K = 0.02$			$K = 0.005$			$K = 0.001$		
	X_2, cm											
	10^{-5}	$5\cdot10^{-5}$	10^{-4}	10^{-5}	$5\cdot10^{-5}$	10^{-4}	10^{-5}	$5\cdot10^{-5}$	10^{-4}	10^{-5}	$5\cdot10^{-5}$	10^{-4}
0.01	256.0	60.0	32.0	437.0	90.5	46.0	480.0	97.0	49.0	497.0	100.0	50.0
0.05	60.0	14.	8.0	90.5	19.0	10.0	97.0	20.0	10.0	100.0	20.3	10.3
0.1	32.0	8.0	4.0	46.0	10.0	5.0	49.0	10.0	5.3	50.0	10.3	5.3
0.5	8.0	2.0	1.3	10.0	2.3	1.4	10.0	2.3	1.4	10.3	2.4	1.4
1.0	4.0	1.3	1.0	5.0	1.4	1.0	5.3	1.4	1.0	5.3	1.4	1.0

---

[*] It is necessary to note that Smith formula, given in the text of work [2], has a mistake: instead of $(2n - 1)$ coefficient it should be $(2n + 1)$. This mistake was automatically transferred into N.N. Prokhorov works [3, page 377] et al. At the same time in appendix to work [2] the formula is written correctly.

In welding of nickel alloy (INCONEL 690) the solidification cracks also appear due to formation of intragranular liquid layers [5], in our opinion, also saturated with sulfur due to small coefficient $K^S_o \approx 0.001$ in nickel. Thus, the results of carried experiments show that studied elements rise welds susceptibility to crack formation in welding of copper-nickel alloys and monel. As the surface active elements they decrease deformation capability of solidified metal [6], and, as a result, due to appearance of effect of adsorption decrease of ductility and strength, promote formation of solidification cracks.

Conclusions

1. Investigated was an effect of main impurities (lead, phosphorus and bismuth) on susceptibility of copper-nickel alloys to formation of hot cracks, their intercrystalline nature was determined. Significant enrichment by sulfur (in 27 times) of crack surface in monel welding was shown.

2. It is determined that oxygen in welding and surfacing of monel in contrast to low-carbon steel intensifies detrimental effect of sulfur.

3. It is proved that detrimental impurities the same as in copper welding promote formation of solidification cracks due to the fact of being surface active elements and manifestation of effect of adsorption decrease of ductility and strength.

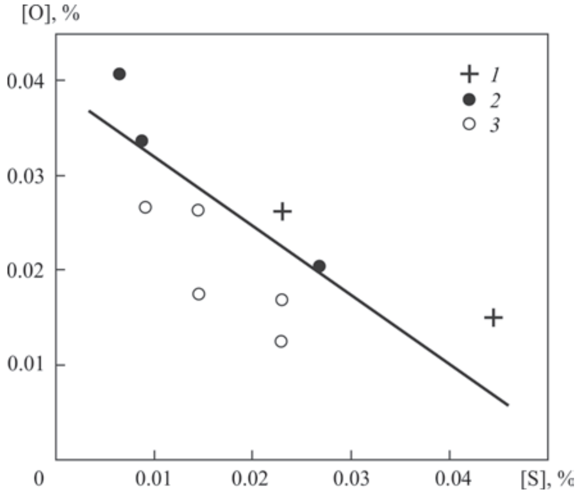

Figure 4. Joint effect of sulfur and oxygen content in weld metal on formation of cracks in deposition of monel on steel: *1* — cracks; *2* — microcracks; *3* — no cracks

1. Anoshin, V.A., Ilyushenko, V.M., Bondarenko, A.N. et al. (2014) Integrated evaluation of effect of main impurities on weldability of copper. *The Paton Welding J.*, **11**, 24–27.
2. Smith, V.G., Tiller, W.A., Rutter, G.W. (1955) A mathematical analysis of solute redistribution during solidification. *Canad. J. Phys*., 33(**12**), 723–745.
3. Prokhorov, N.N. (1968) *Physical processes in metals during welding. Vol. 1: Elements of physics of metals and solidification process.* Moscow, Metallurgiya [in Russian].
4. Podgaetsky, V.V., Parfesso, G.I. (1977) *Cracks of sulfide origin in welding of steel*. Kiev, Naukova Dumka [in Russian].
5. Yushchenko, K.A., Savchenko, V.S., Chervyakov, N.O. et al. (2011) Comparative evaluation of sensitivity of welded joints on alloy Inconel 690 to hot cracking. *The Paton Welding J.*, **11**, 2–7.
6. Anoshin, V.A., Gurevich, S.M., Ilyushenko, V.M., Baranova, V.N. et al. (1981) Effect of surface-active elements on deformation capacity of nickel and monel. *Avtomatich. Svarka*, **7**, 46–48 [in Russian].

Received 28.02.2018