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EFFECT OF RHENIUM ON THE STRUCTURE AND PROPERTIES OF THE WELD METAL OF A MOLYBDENUM ALLOY

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Welded joints in molybdenum and low-alloy molybdenum materials possess low plasticity. Their failure at room temperature is of the brittle type. Experimental molybdenum alloys with improved weldability have been prepared recently. However, as a rule, the heat resistance of these alloys is relatively low. The most heat resistant molybdenum alloys become brittle as the result of welding.

In references (1,2) it was shown that the plasticity of welded joints in molybdenum and low-alloyed molybdenum can be increased by alloying the weld metal with rhenium by using a filler metal. With increased rhenium concentration, the plasticity of the weld metal increases and reaches its highest level at a content of 40-50% Re by weight (the flexural angle of the weld metal is 70-180° at room temperature). The main effect in alloying with rhenium, however, consists of the fact that the weld metal becomes subject to tough fracturing.

There still is no single viewpoint in regard to the causes of increased molybdenum plasticity when aloyed with rhenium. (3-5).

It is assumed that plasticity can increase as the result of a change in the solubility of the interstitial alloying solution, a change in composition, the nature of oxide distribution, and the appearance of a new deformation mechanism -- twinning in the body centered cubical crystal lattice of the solid solution based on molybdenum. In the opinion of the author of reference (5), twinning, on the contrary, decreases plasticity by promoting the formation of microcracks.

The purpose of this work was to investigate the structure and properties of welded joints in a VM-1 type molybdenum alloy (modified) as a function of rhenium concentrations in the weld metal. Sheets of molybdenum alloy were welded by automatic arc welding in a controlled atmosphere chamber. In the process of welding, the weld metal was alloyed with various amounts of rhenium. Rhenium in the form of 1.5 mm wire, foil, as well as 1.5 mm wire of the alloys Mo-47%Re and Mo-52%Re were used as filler metal.

The structure and properties of the weld metal were studied by means of microstructural, electron microscopy and X-ray spectral analysis, as well as by autoradiography and through determination of hardness and plasticity.

X-ray spectral analysis of the welds containing about up to 40% Re by weight showed that rhenium is distributed evenly through the weld cross-section regardless of the form of the filler metal (Fig. 1).

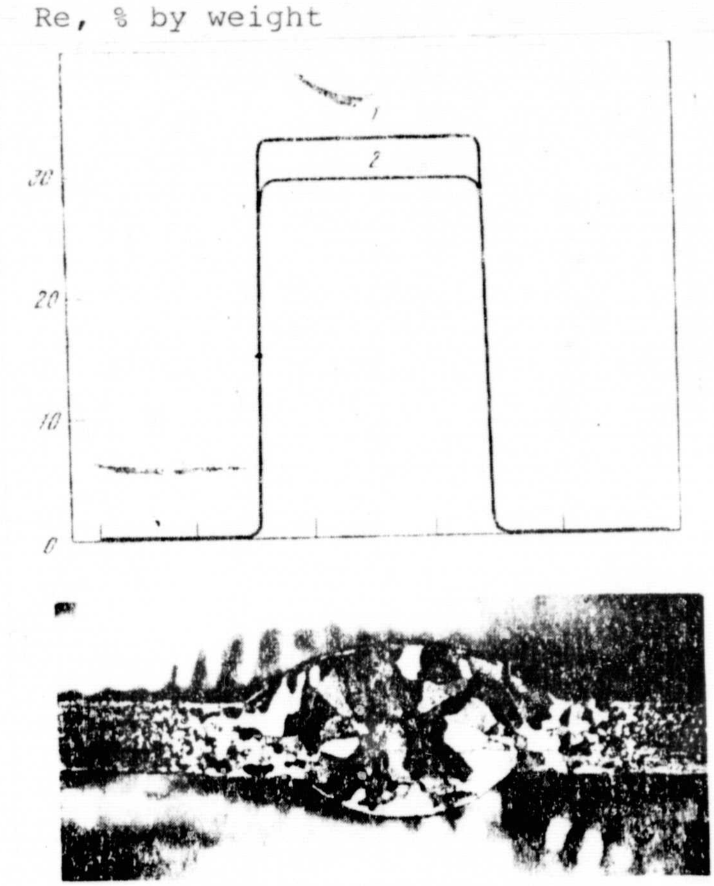

Fig. 1. Distribution of rhenium through the cross-section of a weld, using a rhenium wire (1) and MR-47VI alloy (2) as filler metal.

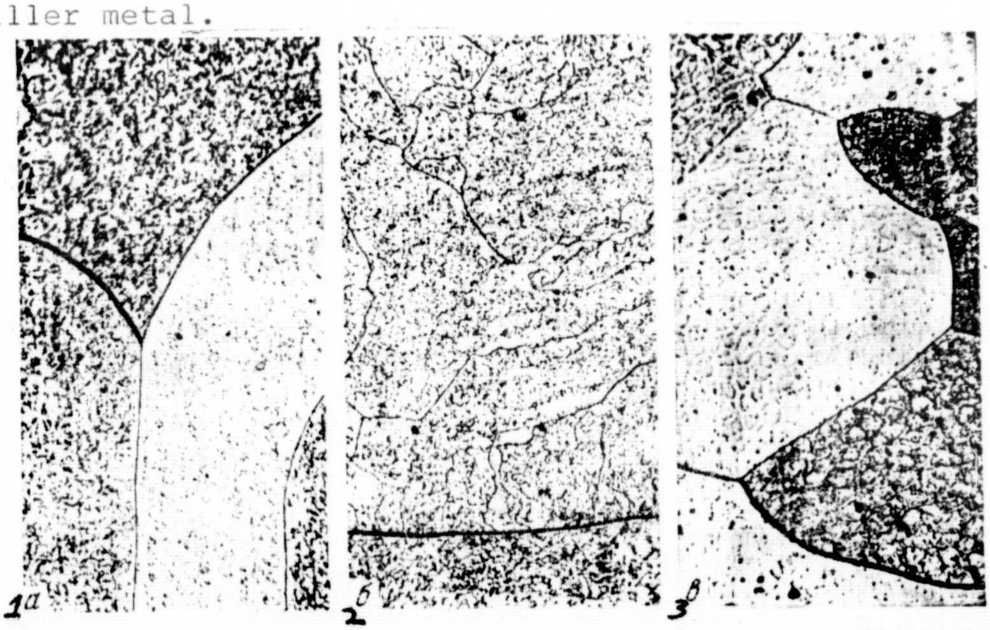

Fig 2. Weld metal structure (manual argon-arc welding with a cover gas jet) of the VM-1 modified rhenium alloys, x200.
1 - 22-23 % by weight; 2 - 32%; 3 - 52%.

The addition of rhenium leads to noticeable changes in the weld metal structure, in particular to a change in the nature of distribution of the second phase, which is formed as the result of the breakdown of the supersaturated solid solution of the alloying material in the molybdenum. In order to obtain a more contrasting picture, a series of samples was welded by the usual argon-arc method in air. Due to insufficiently reliable cover of the welding zone, intensive interaction of the melted metal with atmospheric gases was observed in this case. Here the amount of alloying admixture in the weld metal increases considerably. Fig. 2 shows the microstructure of the weld metal welded manually by the argon-arc method, containing various amounts of rhenium. With a content of up to 20% by weight Re the weld structure shows a large quantity of dispersed second phase precipitation, which indicates a high degree of breakdown of the alloy solid solution. The plasticity of the metal in this case is very low. During bending such a weld undergoes brittle failure at a flexural angle of practically zero. Increasing the Re concentration to 30-32% by weight leads to the appearance of a developed lattice of polygonzed boundaries. the development of the polygonization process indicates an increase in the mobility of dislocations, which is apparently the result of a reduction in the number of barriers inhibiting their movement. The plasticity of weld metal containing 30-32% Re increases. The flexural angle of the welded joint reaches 30-33%. With this, the weld begins to undergo tough fracturing. The structure of weld metal containing 52% by weight Re shows a sharply reduced quantity of second phase precipitation.

A lattice appears within the grains, probably caused by the nucleation of the σ -phase. The flexural angle of such a weld is 18-22°.

The change in the quantity and nature of the second phase precipitation out of a supersaturated solid solution of the interstitial alloy during alloying the weld with rhenium is confirmed by electron microscopy studies as well (Fig. 3). In the weld metal unalloyed with rhenium (1) [welding in a controlled atmosphere chamber] there is a large quantity of finely dispersed particles of oval or elongated shape, located either along or near grain boundaries. The picture changes sharply as the result of adding 49% by weight Re to the weld metal (2). The boundaries and the grains themselves become more pure. Relatively large precipitation areas are encountered only occasionally. The plasticity of such a weld increases to several times over that of an unalloyed one. The flexural angle values increase from 8-16 to 55-90°.

On the basis of the results obtained it can be supposed that in alloying a molybdenum alloy with rhenium, the behavior of the intersticial alloy components is sharply altered, and this is one of the causes of increased plasticity.

In our opinion, the most harmful impurity in molybdenum is carbon. An autoradiography technique was used to check the effect of rhenium on the behavior of carbon in the weld metal. Ingots of a molybdenum alloy were smelted, to which the radioactive carbon isotope C^{14} was added. After the smelting the ingots were reduced to a thickness of 1.5 mm, cut into platelets and welded together automatically inside a chamber. Samples were welded together from the platelets without rhenium and with an addition of 20% and 50% Re by weight to the weld metal. The results of autoradiographic studies (Fig.4) showed that in all cases considerable decarburization took place during the welding process. Due to the high cooling rates in the welding, no noticeable carbon enrichment of the grain boundaries in the weld metal occurred.

In the unalloyed (1) as well as in the 23% Re content welds (2) both carbon-depleted and carbon-enriched zones are found in cross section. Decarburization is observed primarily in the zones of fusion with the primary metal, as well as in the regions of double remelting (with welding from both sides). With a high rhenium content (Fig. 4,[3]) the carbon distribution throughout the weld becomes more uniform, but in the double remelting section, nearly complete decarburization takes place. At the same time, it should be noted that no changes in microhardness were observed through the weld depth. Apparently, this can be explained by the fact that the carbon content in the alloy is very low, and that those changes in its concentration which occur during the welding process do not significantly affect the hardness of the weld metal.

In our opinion, the decrease of carbon content in the weld metal during its alloying with rhenium can occur either as a result of the formation in the Mo-Re-C system of a complex carbide which is less refractory or less strong than Mo_2 carbide, or due to formation of volatile rhenium oxides, during the dissociation of which carbon oxidation is possible.

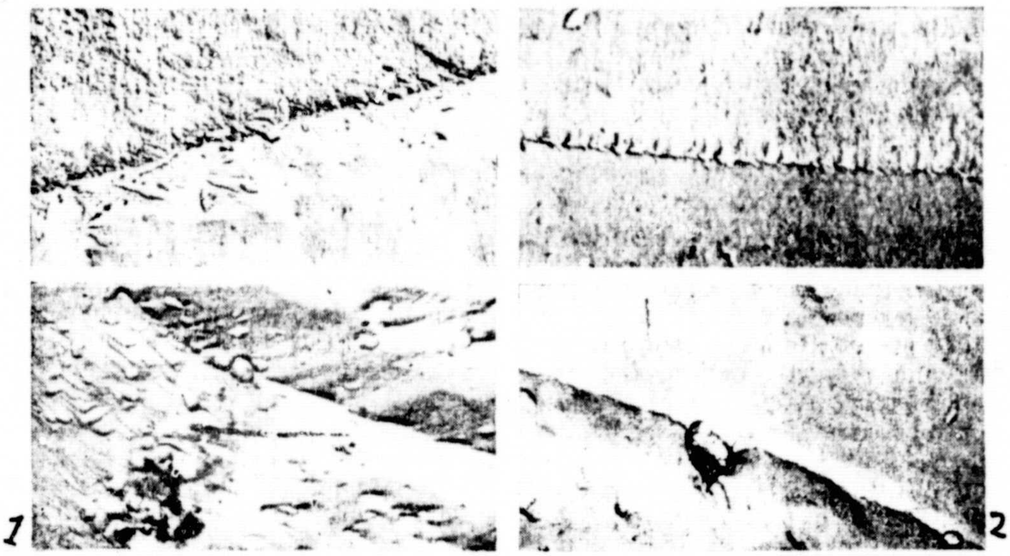

Fig. 3. Effect of rhenium on the nature of second phase precipitation in welds in VM-1 modified alloy. x10,000
1 - unalloyed weld; 2 - 49% Re by weight in the weld metal.

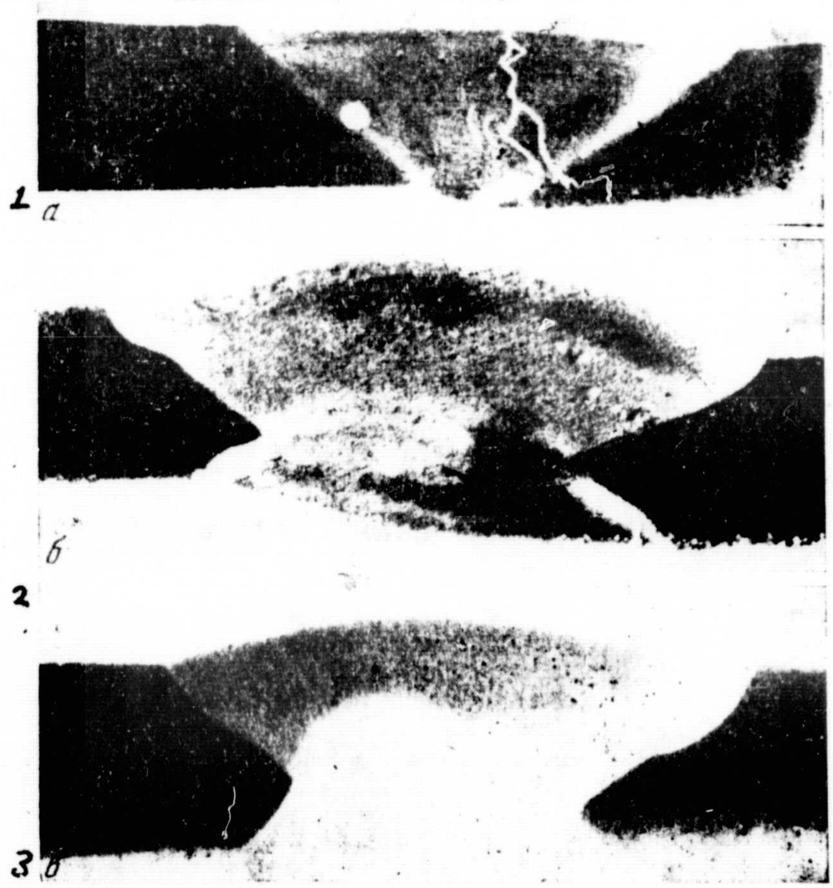

Fig. 4. Carbon distribution in weld metal. x13
1 - molybdenum; 2 - 23% Re; 3 - 50% Re.

Conclusions

It was shown that the plasticity of the alloy increases sharply with increasing the rhenium content up to 50% by weight in the weld metal of a molybdenum alloy. During the welding process, decarburization of the weld metal was observed, with its intensity increasing with increased rhenium concentration.

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16. Abstract
Study of the structure and properties of welds made in molybdenum alloy VM-1 as a function of rhenium concentrations in the weld metal was carried out. Rhenium was introduced into the weld using rhenium wire and tape or wires of Mo-47Re and Mo-52Re alloys. The properties of the weld metal were studied by means of metallographic techniques, electron microscopy, x-ray analysis and autoradiography. It was found that the plasticity of the weld metal sharply increases with increasing concentration of rhenium up to 50%. During welding, a decarburization process was observed which was more pronounced at higher concentrations of rhenium.

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