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NARROW-GAP TIG WELDING OF THICK STEEL 20

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ABSTRACT

Arc welding of joints of carbon steels 20–100 mm thick can be performed both by consumable and nonconsumable electrode, using shielding gases or flux. In order to increase the efficiency of welding operations, multilayer narrow-gap welding (NGW) with filler wire feeding can be used for metals of medium and large thicknesses. This study deals with application of tungsten electrode NGW process with and without superposition of a controlling magnetic field for welding samples from steel 20 of 40 mm thickness. Results of investigations of the macro- and microstructure and microhardness of the welded joints are given. It was found that application of an external controlling magnetic field for NGW of steel 20 joints ensures a higher quality of the welded joints.

KEYWORDS: narrow-gap argon-arc welding, tungsten electrode, steel 20, controlling magnetic field, structure, microstructure, microhardness

INTRODUCTION

Arc welding of joints of carbon steels 20–100 mm thick can be performed both by consumable and nonconsumable electrode with application of shielding gases or flux. At present tungsten electrode welding is believed to be a reliable, but an unproductive process of arc welding of thick butt joints. One of the methods to improve the productivity of welding operations for different metals of medium and large thickness is narrow-gap multilayer welding, namely NGW with filler wire feed. Its special feature is the shape of edge preparation in the form of a rectangular slot, in which one bead is deposited on the other by the arc process across the entire width of the gap. It results in formation of a metal layer, which fills the gap to a certain height. Successive performance of these operations leads to filling the entire volume of the gap by the deposited metal [1, 2]. The main advantages of NGW are a significant reduction of the required quantity of the deposited metal (compared to treatment of edges of a regular shape), reduction of filler wire consumption, weld width, and HAZ width, as well as decrease of welding stresses and strains [2]. NGW of steel parts is mainly performed with application of consumable electrode welding technology [3]. To produce sound welded joints, it is necessary to ensure reliable melting of the side walls at NGW and fusion of the weld metal with the base metal [5, 6]. In consumable electrode welding deformed wire or welding with filler wire oscillation, and welding with filler wire rotation are used [3, 7, 8]. The process of consumable electrode NGW has such an advantage over tungsten electrode NGW, as a higher productivity [4].

PWI developed a technology of tungsten electrode NGW which has proven itself well for welding titanium and some other nonferrous metals [1, 9]. Successful realization of this process requires overcoming certain difficulties, the main of which is ensuring reliable melting of the groove side walls. To ensure reliable melting of the side walls, it is necessary to redistribute the thermal energy between the edges being welded. With this purpose both mechanical displacement of the tungsten electrode and external magnetic field can be used at NGW [10]. As carbon steels have their own magnetic field and high magnetic properties, application of an external controlling magnetic field for NGW becomes complicated, as the own magnetic field of the parts being welded, can be superposed on the external controlling magnetic field, formed by the magnetic system of the welding head.

OBJECTIVE OF THE WORK

Was to study the possibility of performance of tungsten electrode NGW with an external controlling magnetic field of welded joints of 40 mm carbon steel.

INVESTIGATION METHODS AND MATERIALS

Welding of 40 mm thick samples from steel of grade 20 to GOST 1050–88 was conducted to study the possibility of tungsten electrode NGW performance. Filler wire of 1.6 mm diameter of Sv-08G2S grade was used for welding. Welding was conducted both without an external controlling field, and with an external controlling magnetic field. The process schematic is shown in Figure 1. Welding was performed by 5 mm tungsten electrodes of EVI-1 grade. VDU501 welding power source was used. Welding current was 460–500 A, arc voltage was 12 V, rate of feeding the filler metal of 1.6 mm Sv-08G2S wire

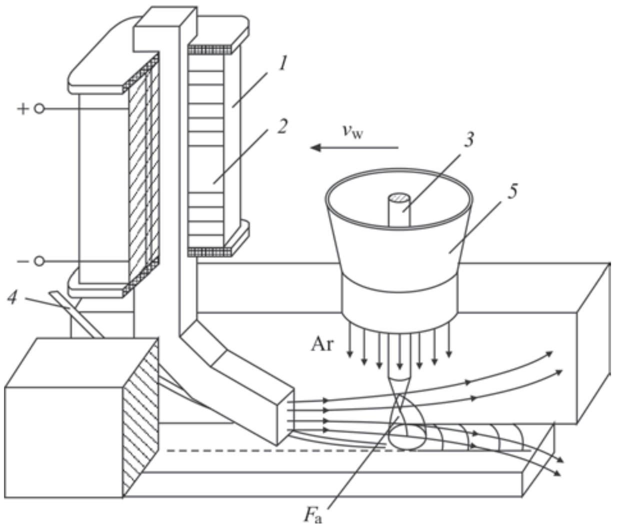

Figure 1. Schematic of the process of tungsten electrode NGW with application of an external controlling magnetic field: *1* — electromagnet coil; *2* — electromagnet core; *3* — tungsten electrode; *4* — filler wire; *5* — protective nozzle

into the weld pool was on the level of 20–25 g/min. The set arc voltage was maintained by an automatic system, which adjusted the arc voltage. Welding arc deflection to the side walls was ensured by superposition of an external magnetic field of 10–20 Hz frequency, which is generated by an external electromagnet (Figure 1). The welding process and tungsten electrode position in the groove were controlled by a videorecording system (Figure 2). Figure 2 shows the schematic of sample set-up for NGW, the substrate for sample set-up was also made from steel 20. Length of samples for welding was equal to 600 mm.

INVESTIGATION RESULTS

Tungsten electrode NGW is characterized by participation of a large fraction of filler metal in weld metal formation, in our experiments it was equal to ~ 90 %, so that the properties of metal of NGW welded joints are determined mainly by the properties of filler wire material and influence of the external controlling magnetic field.

Metallographic investigation of transverse macrosections did not reveal any pores in the metal of the weld produced with an external controlling magnetic field. The metal of the weld made without an external controlling magnetic field and without redistribution of thermal energy of the welding arc, contained lacks of fusion, lacks of penetration and individual pores were observed.

Photographs of transverse macrosections of the produced welded joints are given in Figure 3.

Conducted metallographic investigations of joints made by NGW without application of an external controlling magnetic field with filler material feeding at the rate of 20–25 g/min showed that the welds had great depth of penetration of the lower wall of the

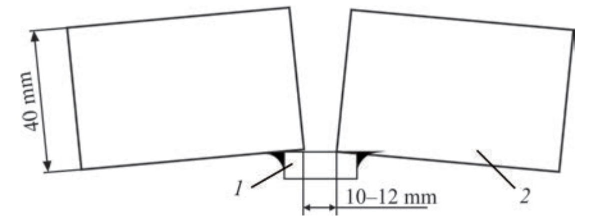

Figure 2. Schematic of sample set-up for tungsten electrode narrow gap welding: *1* — substrate; *2* — samples to be welded

groove and small width in the lower part, the welds had lacks of penetration and lacks of fusion (Figure 3, *a*). Penetration of the vertical side walls turned put to be nonuniform, as was the shape of the deposited layers, which is related to appearance of such defects as lacks of penetration and lacks of fusion. Application of a magnetic field for welding arc deflection ensured uniform penetration of the side walls and sound weld formation (Figure 3, *b*). Deposited layers have a smooth concave surface, which is indicative of reliable fusion of the filler and base metal. Penetration of the base metal and the previous bead is small. X-ray inspection of the welded joints produced using an external controlling magnetic field in the optimal modes did not reveal any lacks of penetration, lacks of fusion or pores in the metal of the weld, made with application of an external controlling magnetic field.

Alongside the influence of an external controlling electromagnetic field ((ECEMF) on the welded joint macrostructure, of considerable interest is evaluation of the impact of such a treatment on its microstructure. Presence of such an impact was established in many investigations, in particular works [11, 12, 14] give a review of treatment variants and possible mechanisms of the magnetic field influence on the alloy microstructure. Note that there is no single generally accepted mechanism describing the influence of the field. This is related to the fact that there exist many variants of treatment technology and it is applied for

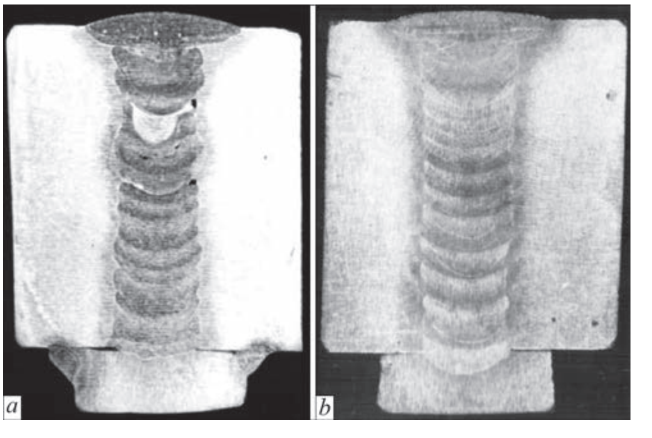

Figure 3. Transverse macrosections of joints of carbon steel 20 produced by tungsten electrode NGW: *a* — without an external controlling magnetic field; *b* — with an external controlling magnetic field

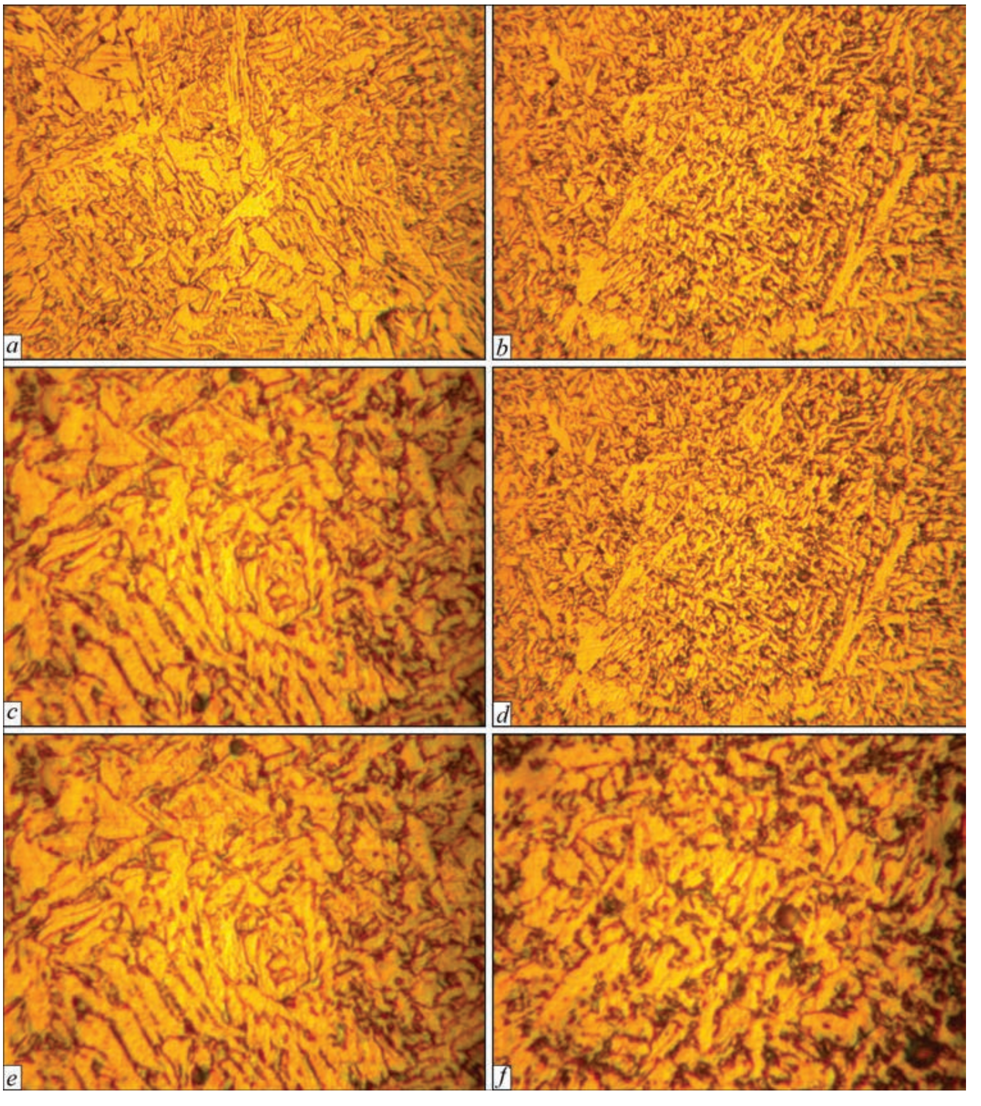

Figure 4. Microstructure of metal of the weld without the impact (*a*, *c, e*) and with the impact (*b*, *e*, *f*) of an external magnetic field: *a*, *b* — ×200; *c*, *d* — ×500; *e*, *f* — ×1250

alloys of different chemical composition with different physical properties (ferromagnetic and nonferromagnetic materials). Therefore, there can be several variants of the influence mechanism, depending on such factors as specific power of the field, frequency, duration and temperature range, in which treatment is conducted. However, the most certain fact is that ECEMF superposition leads to structure refinement.

Figure 4 gives the microstructure of weld metal, not subjected to the impact (ECEMF) and of the weld made under the conditions of the field application. One can see that a homogeneous dispersed structure forms in both the cases at magnification ×200 (Figure 4, *a*, *b*). No obvious difference between the structures is revealed. However, at magnifications ×500 (Figure 4, *c*, *d*), it can be seen that ECEMF impact makes the structure more dispersed. Another feature of ECEMF impact becomes obvious when magnification ×1250 is used (Figure 4, *e*, *f*). It consist in that the grain morphology also changes in addition to structure refinement, and they transform from elongated (Figure 4, *e*) into equiaxed ones (Figure 1, *f*). Such an influence of the field was earlier revealed when studying the crystallization of nonferromagnetic material (tin bronze) [13], but the data of this analysis suggest that this effect is of a more general nature.

Manifestation of this effect is also visible at analysis of the fusion zone structure (Figure 2).

At magnification of ×50 (Figure 5, *a, b*) a primary dendritic structure of the metal is revealed in the fusion zone, which in both the cases is similar and ECEFM effect is not obviously manifested, but at magnifications ×500 (Figure 5, *c*, *d*) and ×1250 (Figure 5, *e*, *f*) one can see that the microstructure becomes more dispersed and pearlitic colonies practically disappear, being replaced by a uniformly distributed carbide phase.

Microhardness distribution of the metal of welded joints from steel 20 made both with and without ECEMF impact was conducted, using PMT-2 microhardness meter with 100 g load (Figure 6).

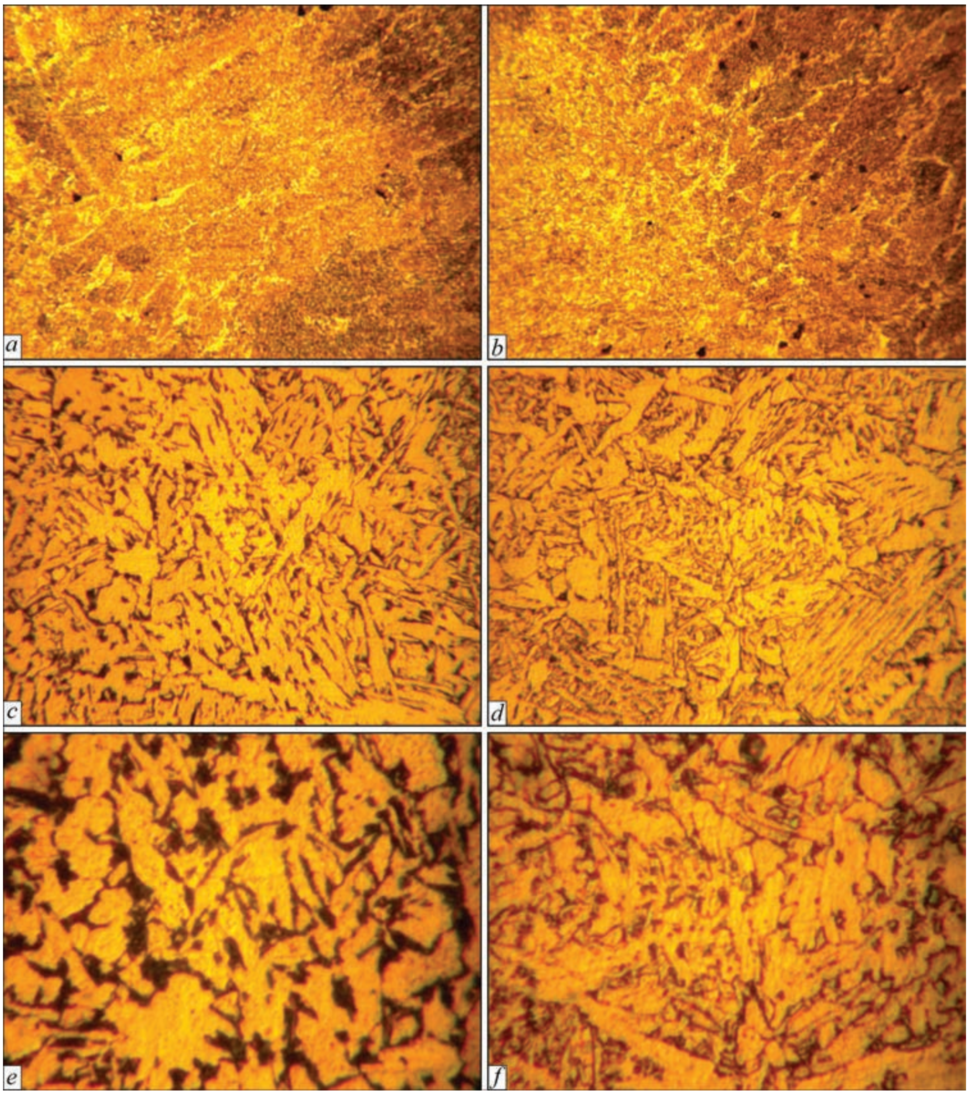

Figure 5. Microstructure of metal of the fusion zone without the impact (*a*, *c*, *e*) and with the impact (*b, e*, *f*) of an external controlling magnetic field: *a*, *b* — ×50; *c*, *d* — × 500; *e*, *f* — × 1250

Microhardness values of base metal (steel 20) are on the level of 1700 MPa (Figure 7 and Figure 8). In the metal microhardness values are on the level of 2000 MPa on average, which, in its turn, is most probably related to formation of a new hardening structure. Microhardness of metal in the weld produced without the magnetic field impact is on the level of 2300 MPa (Figure 7), and that of the metal of the weld, produced under the impact of an external magnetic field is on the level of 1900 MPa (Figure 8). This may be related to the fact that during external magnetic field application a more fine-grained structure forms with a

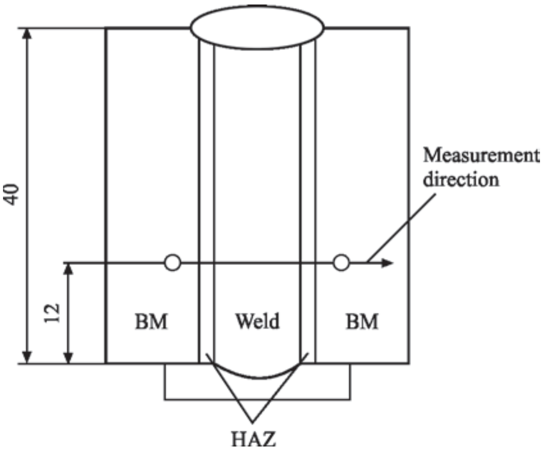

Figure 6. Schematic of measurement of microhardness distribution in the welded joint of steel 20 produced by NGW with 1.6 mm Sv-08G2S filler wire

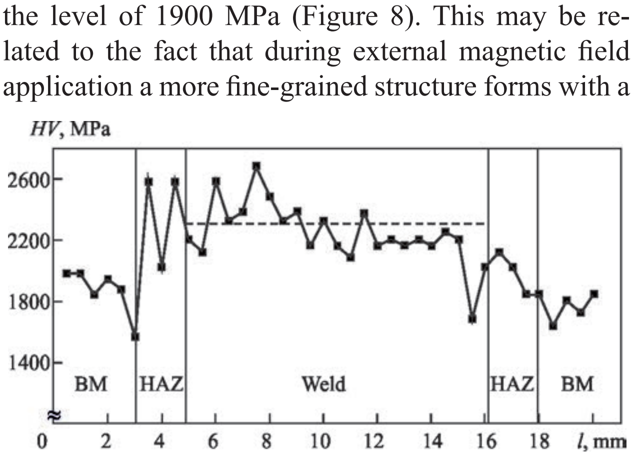

Figure 7. Microhardness distribution in the welded joint of steel 20, produced by NGW with 1.6 mm Sv-08G2S filler wire, without ECEFM impact in as-welded condition

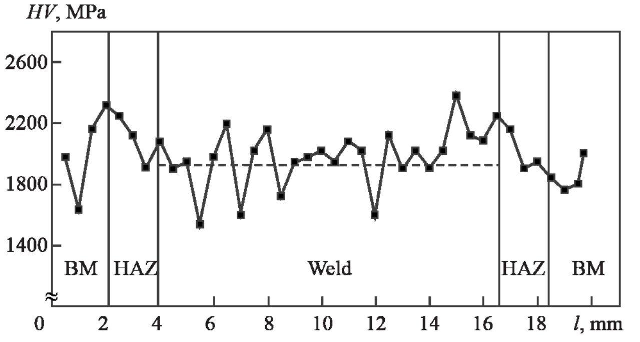

Figure 8. Microhardness distribution in the welded joint of steel 20 in as-welded condition, produced by NGW with 1.6 mm Sv-08G2S filler wire and ECEMF impact

changed morphology of the cementite phase. Carbide particles do not form colonies with lamellar morphology, but they are uniformly distributed in the ferrite. As a result, the weld metal produced by such a method has higher ductility and lower microhardness than the same sample produced without the influence of the external magnetic field.

DISCUSSION OF THE RESULTS

Technology of tungsten electrode NGW with an external controlling magnetic field, which has earlier proven itself well for welding titanium and some other nonferrous metals can be applied for welded joints made from magnetic steels, such as steel 20 of 40 mm and greater thickness. Magnetic control of redistribution of thermal energy of the welding arc fulfills its function — welding arc deflection and anode spot shifting to the required value, which ensures absence of lacks of penetrations, lacks of fusion, and pores in the welds. Side wall penetration is uniform with good weld formation. In welds made without application of magnetic control and without redistribution of the arc thermal energy, numerous defects are recorded, namely lacks of penetration and lacks of fusion. Application of NGW with magnetic control of the welding arc also allows increasing the deposition rate and raising the feed rate of filler metal of 1.6 mm Sv-08G2S wire into the weld pool to the level of 35 g/min. The authors failed to perform deposition by the process of tungsten electrode NGW without magnetic control with such a feed of filler metal. Thus, application of magnetic control of the welding arc allows somewhat compensating the main disadvantage of tungsten electrode argon-arc welding — the low deposition rate. More over, investigations of welded joint microstructure and establishing the microhardness distribution in the metal of steel 20 welded joints produced both under the impact of ECEMF, and without it, led to the conclusion that, on the whole, the level of microhardness in the weld with ECEMF impact is characterized by a high uniformity, without any significant gradients or excess hardening of the weld zone, compared to hardness distribution in a sample produced without ECEMF impact. This allows expecting a higher resistance of welded joint metal to the impact of dynamic and cyclic loads.

Thus, ECEMF application during welding not only allowed preventing formation of weld macrostructure defects, but also had a positive impact on its microstructure. Further investigations should be aimed at establishing the dependence of microstructural characteristics on ECEMF parameters, in order to enhance the observed effects.

CONCLUSIONS

1. Joints from 40 mm thick steel 20 were welded using the technology of tungsten electrode NGW with an external controlling magnetic field, which had earlier proven itself well for welding titanium and some other nonferrous metals.

2. Investigations of welds produced by tungsten electrode NGW with application of an external controlling magnetic field showed a practically complete absence of lacks of penetration, lacks of fusion and pores in the welds with uniform penetration of the side walls and good weld formation.

3. Performed studies lead to the conclusion about the higher quality of steel 20 welded joints, produced by tungsten electrode NGW with an external controlling magnetic field with filler material feed at the level of 20–25 g/min, compared to tungsten electrode NGW without an external controlling magnetic field.

4. Application of an external controlling electromagnetic field during narrow-gap welding of joints of steel 20 had a positive influence on the joint microstructure. The joint microstructure became more dispersed, pearlitic colonies disappeared, being replaced by a uniformly distributed carbide phase, which is accompanied by achieving a uniform microhardness distribution in the weld metal.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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