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High-Performance Welding Processes – Comparison of Properties and Applications

Abstract: The increasingly high level of productivity entails the growing popularity of high-performance welding methods in production processes. In addition, increasingly high occupational safety-related requirements stimulate the development of automated welding processes. The article compares methods of arc and laser welding technologies as well as presents primary process parameters in relation to values assumed in designs and with reference to permissible tolerances.

Keywords: high-performance welding methods, arc welding. laser welding

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Introduction

In terms of planning and production preparation, the most economic methods used in the joining of thick-walled elements are high-performance processes, including both fusion and pressure welding technologies. The study discussed in the article was primarily concerned with arc and laser beam welding processes, the extensive applications of which were illustrated with examples of implementations at SLV Halle.

Welding process selection conditions

One of the proven high-performance processes is submerged arc welding. Depending on the thickness of a given material, in addition to one wire-based welding process, it is also possible to apply multi-wire welding systems. Multi-wire welding systems (featuring a maximum of five wires) are used, among other things, in the welding of pipes having a thickness of up to approximately 35 mm. The welding rate of the above-named welding process amounts to approximately 2 m/min. Because of its high stability and repeatability, the process serves as a reference point when comparing other joining processes.

Deliberations concerning the joining of thick elements should also include electron beam welding. Elements having a thickness of up to approximately 200 mm can be welded using only one bead, yet such an approach can rarely be combined with design-related requirements. Typical applications of electron beam welding usually involve material thicknesses restricted within the range of 5 mm to 50 mm.

New joining processes having high developmental potential

Alternatives to the above-named well-known joining methods used at SLV Halle include the following process and welding power source-related solutions:

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– high-current arc welding,
– fibre laser (used as a single heat source or in combination with hybrid methods),
– diode laser (used as a single heat source or in combination with hybrid methods).

The applications of the above-presented laser processes are discussed in the remainder of article.

CO_2-shielded high-current welding process

The MAG welding method involving the use of high current restricted within the range of 500 A to 1000 A is referred to as high-current welding. The diameter of the electrode wire used in such a process is restricted within the range of 3.6 to 5 mm. The use of high welding arc power, aimed to obtain deep penetration, requires the application of the electrode wire having a smaller diameter and the use of CO_2 as the shielding gas. To ensure the spatter-free course of the welding processes it is necessary to use welding power sources featuring special pulsed current programmes.

The tests involved the use of two welding power sources (OTC) having a maximum welding current of 500 A. The application of the above-named machines enabled the obtainment of butt joints having a thickness of up to nearly 20 mm. The welding process was investigated both with reference to the making of butt joints and joints, which in accordance with the ISO 5332 standard, can be identified as containing the so-called *flare weld* (i.e. welds of an undefined shape). The aforesaid shape of the weld is typical of structures made of closed shapes being rectangular in cross-section. The rounded corners of the shapes, resulting from the shape production process, lead inevitably to the formation of the aforesaid weld.

Figure 1 presents the shape of the weld in the butt weld cross-section (square butt weld preparation) in relation to various weld widths.

In cases of two-sided welding (Fig. 2), with a slight overlap of the root area, it is possible to obtain greater penetration depth than 35 mm. However, sheets must be welded in the flat position (PA) and be turned upside down.

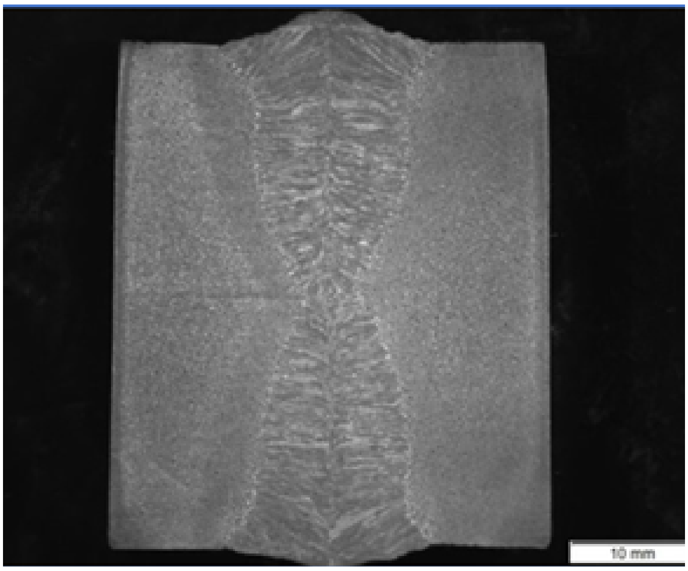

Fig. 2. Macrographic metallographic specimen of the cross-section of the elements subjected to two-sided arc welding process (with deep penetration)

Parameter			
Welding current	620 A	Welding rate	35 cm/min
Arc voltage	44 V	Filler metal wire feed rate	23m/min
Linear energy	4.81 kJ/mm		

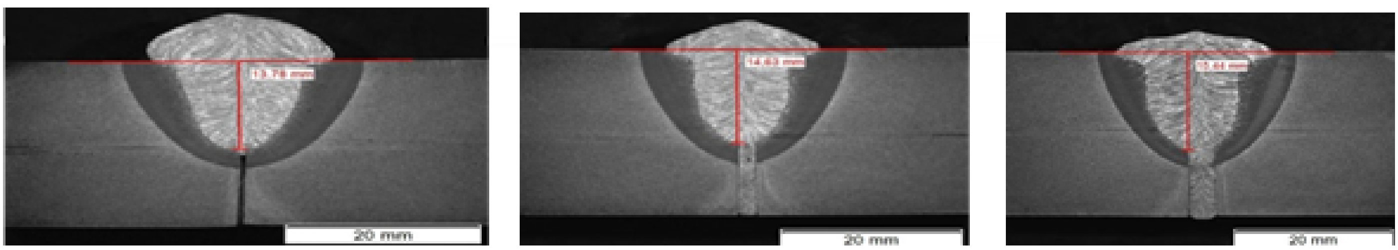

Fig. 1. Macrographic metallographic specimens of the cross-section of elements welded using high-current arc in relation to various sizes of the gap between the elements (square butt weld preparation)

The above-presented process (also known as D-arc welding) can be used to make welds with deep penetration. The shape of the aforesaid welds is similar to that of welds obtained using the submerged arc welding process. The size of the weld pool carries the risk of coarse grain formation, yet the aforesaid phenomenon did not take place in an individual study (performed by the author), which was also demonstrated in process-related tests. However, welding in other positions is nearly impossible as the stability of the liquid metal pool is difficult to control (due to gravity).

	MAG method	D-arc process
Welding current	280 A	600 A
Arc voltage	30 V	48 V
Welding rate	60 cm/min	48 cm/min
Linear energy	2.7 kJ/mm	3.6 kJ/mm

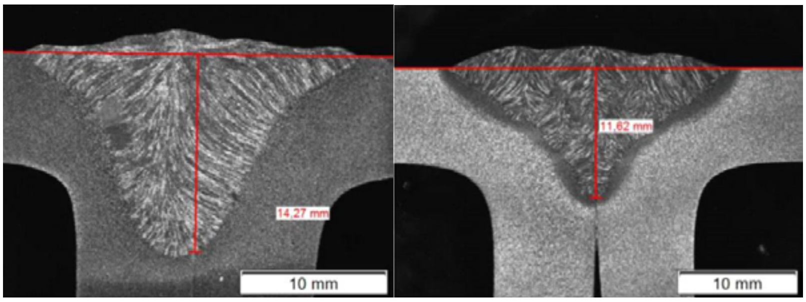

Fig. 3. Comparison of flare welds in accordance with ISO 2553; multi-run MAG weld (a); single-run D-arc weld

Ideal applications can be observed in relation to the high-current joining of semi-finished products, e.g. closed shapes, using flare welds (i.e. welds of undefined shapes - in accordance with ISO 2553) (see Fig. 3).

Laser welding with technological lasers of various power

The control of the weld pool (even in various welding positions) is significantly easier using the laser beam welding process (in comparison with arc-based welding methods). However, in the above-named case it is necessary to distinguish various laser beam power sources and various processes, i.e. where the laser is an independent (separate) heat source or where the laser is used in hybrid processes. Available laser radiation beam sources for deep penetration welding process were the following:

- fibre laser (IPG) having a maximum power of 12 kW, process optical fibres having core diameters of 300 µm and 100 µm; optionally in combination with the MAG welding process,
- diode laser having a maximum power of 15 kW, a process optical fibre having a core diameters of 600 µm; optionally in combination with the MAG welding process.

Tests involving the use of high-power diode lasers have only been performed for the past two years. As a result, the experience gained within the aforesaid period is significantly less impressive in comparison with already possessed vast technological experience concerning the application of various fibre lasers.

Comparison of characteristics of radiation beams of selected laser power sources

A parameter characterising the laser radiation beam as a heat treatment tool is the quality of the beam. The workability of materials is particularly affected by the properties of the focused beam (of a technological laser). The size of the beam is equally important as, for instance, the geometry of the cutting edge of the tool used in the machining process. The research project aimed to identify properties of beams generated by various laser power sources and the development of an algorithm enabling the transfer of welding process parameters to various technological lasers. Table 1 presents results of permanently updated measurements.

The results presented in Table 1 reveal the existence of significant differences as regards radiation beam properties of various technological lasers. Depending on a laser type, the diameter of the beam focus may differ ten-fold (affecting power density in the focus). Resultant welding-related differences were clearly visible in technological tests.

Table 1. Measurements concerning laser radiation beams emitted by various technological lasers

Laserline	Trumpf	IPG	IPG	IPG	Producer	Laser
LDF 15000-60 (process optical fibre: 600 μm)	HL 3006D	YLS 6000 CT (process optical fibre: 300 μm)	YLS 12000 (process optical fibre: 100 μm)	YLS 12000 (process optical fibre: 300 μm)	Model	
86182238		14106650	8112050	8112050	SN	
High-power diode laser	Nd:YAG laser	Fibre laser	Fibre laser	Fibre laser	Type	
920-1080	1064	1070	1070	1070	Wavelength [nm]	
15000	3000	6000	12000	12000	Maximum power[W]	
Halle	Fellbach	Halle	Halle	Halle	Centre	Measurement
27.08.2019	07.03.2018	11.12.2019		26.07.2017	Date	
250	150	300	200	200	Focal length f [mm]	
40	36	21	19	19	Raw beam diameter $2\omega_L$ [mm]	
1566	399	750	168**	473	Focused beam diameter $2\omega_0$ [μm]	
10.020	1.719	10.706	1.77**	4.979	Area reduction length (Rayleigh length) z_R [mm]	
181.70	68.35	38.90	11.74**	32.94	Diffraction coefficient M^2	
0.01	0.01	0.03	0.09**	0.03	Propagation coefficient k	
61.31	23.15	13.13	4.00**	11.22	Beam parameter product BPP [mm·mrad]	

Fibre laser welding

High-power fibre lasers (having a power of several kilowatts) have been available on the market for approximately 20 years. The reliability of industrial applications required not only the availability of laser radiation beam sources, but also the further development of laser devices in terms of easy operation and maintenance. The above-named trend has been observed for the past 15 years. Presently, fibre lasers are widely used in industry and, to a large extent (but not entirely), have replaced CO_2 lasers in welding applications. One of the advantages resulting from the use of fibre lasers is the wavelength of the radiation beam (affecting occupational safety and process screening).

Because of their compact design, easy operation, favourable running costs and the possibility of optical fibre-based process integration, fibre lasers may significantly increase their share on the market. An attractive feature of the technological fibre laser (in users' eyes) is its nearly unlimited power; a restricting factor being the length of the optical fibre resonator (where presently obtainable output power reaches as many as 50 kW). Lasers having such a high power cannot be used in welding processes as laser radiation beam power density is so high that the energy coupling of the laser beam and the surface of the metal leads to the uncontrollable evaporation of the latter. The foregoing results in the uncontrollable ejection of the metal from the weld area (still under formation) and, consequently, the formation of entirely imperfect welds. The above-presented observation was confirmed by individual technological tests, performed using a source having a power of 20 kW (BAM).

Diode laser welding

In terms of physical aspects, the diode laser has an advantage not only over the CO_2 laser but also over the fibre laser. The wavelength of radiation emitted by the diode laser is lower, which translates into significantly more favourable radiation absorption (particularly in terms of metallic materials). The use of diodes is also more convenient because of electric efficiency. Because of its easy design, the generator of laser radiation is easy to use. A disadvantage of the laser is the relatively lower quality of the “raw” radiation beam (i.e. unformed by the optical system – author’s remark). As can be seen, the properties of the focused diode laser beam continue to be problematic. This issue is particularly visible in relation to high power, where (in today’s laser radiation source designs) several combined modules (composed of laser bars containing single emitters – author’s remark) form one working beam (requiring high precision of the laser optical system).

Application of the laser beam in keyhole welding processes

Applications of the laser beam in keyhole welding processes can be found in the manufacturing of heavy vehicles. Figure 4 presents the possibility of making a flare weld (in accordance with ISO 3552) using the diode laser.

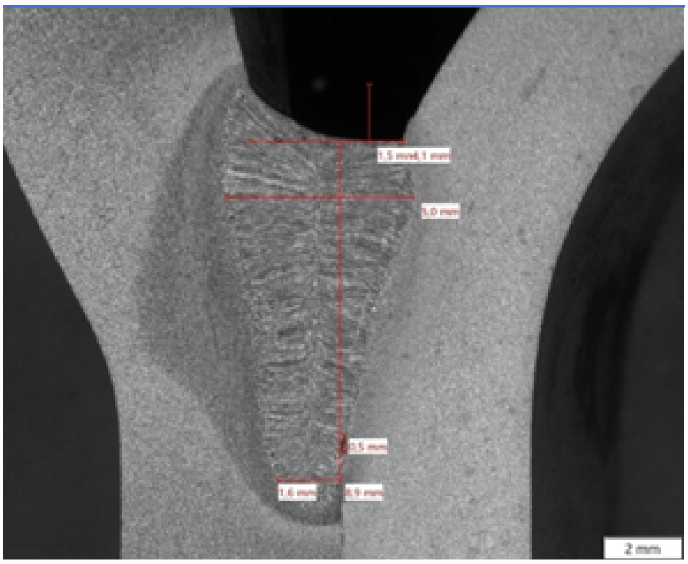

Fig. 4. Exemplary application of the laser beam in the making of a hard-to-access joint

It is possible to make a weld having a thickness of 10 mm, which is also required because of existing loads. In cases of such structures made of sheets it is also necessary to take into consideration matching-related tolerances resulting from sheet deformation. In the above-presented situation, the diode laser is a preferable welding power source. Favourable absorptive properties of radiation are favoured by the shape of an element. The larger beam diameter is more favourable as it more effectively covers the material in the gap area (located between the matched elements).

Figure 5 presents a joint between a nozzle and a tube. The distribution of hardness presented in Figure 6 reveals different materials (of the elements). Such a joint can be made in the flat position, yet the reliability of the process is significantly higher if the process is performed in the horizontal position. The foregoing coincides with experience gained in relation to the electron beam welding process.

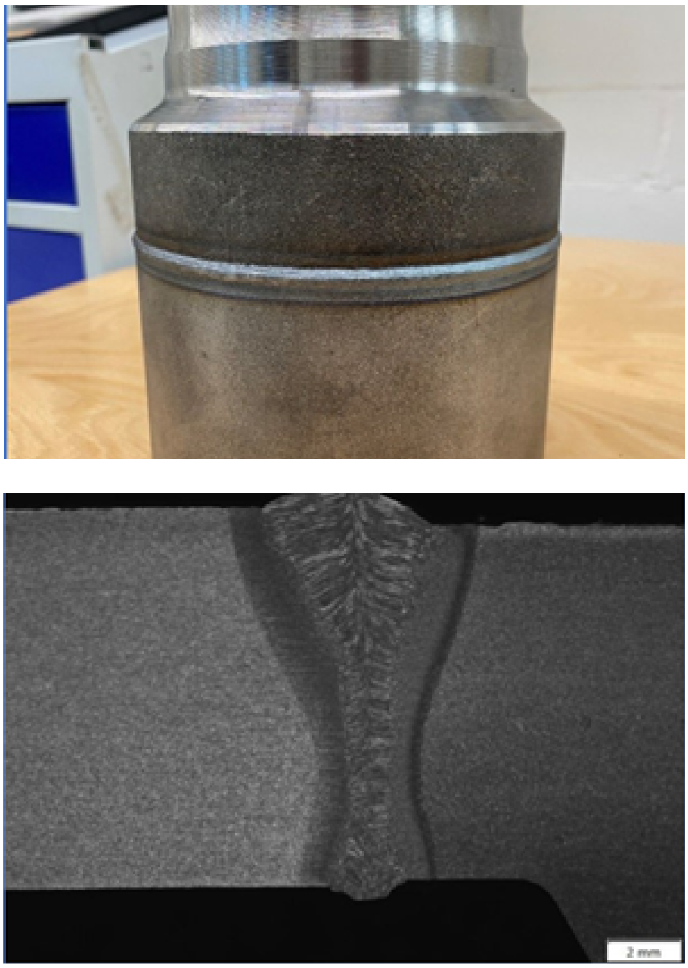

Fig. 5. Joint: nozzle – tube

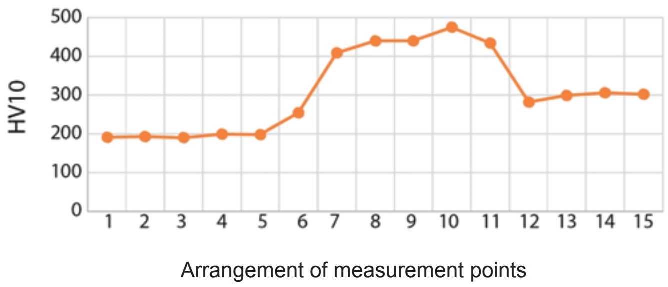

Fig. 6. Hardness distribution in the cross-section of the weld of the joint made of two different types of steel (Fig. 5)

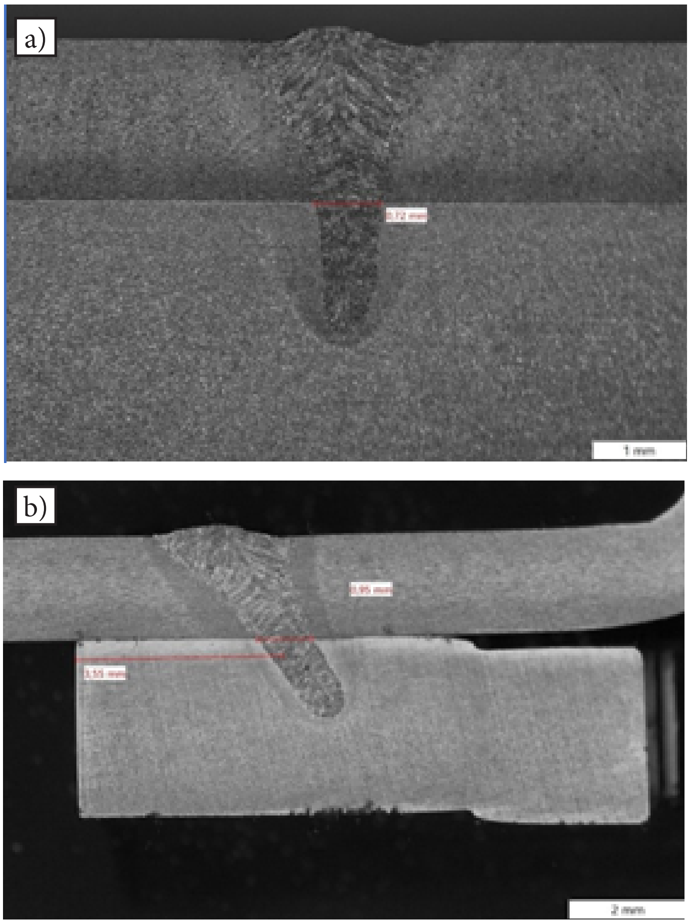

Fig. 7. Welds in the overlap joint made using the laser beam positioned at various angles: perpendicular position of the laser beam (a) and the laser beam positioned at an angle of 45° (b)

An additional heat input resulting from the use of the hybrid laser welding process may positively affect the hardness of the weld deposit.

In overlap joints, due to the transfer of forces, the width of the weld at a specific depth is an important factor. The example presented in Figure 7 shows the method, by means of which it is possible to control the weld width using the high-power laser radiation beam affecting the material surface at various angles. A given variant should be selected taking into consideration the accessibility of the joint area. By using an additional MAG welding power source, the joining process is "supported" by additional arc power restricted within the range of 30% to 50%.

The high-power laser beam welding of pipelines is usually performed under difficult conditions (i.e. on the construction site). Pipes having 6 mm thick walls are welded without the filler metal, using the fibre laser having a power of 6 kW. More information concerning this issue can be found in publication [2]. An exemplary technological laser application on the construction site is presented in Figure 8.

Fig. 8. Laser beam orbital welding performed on the construction site

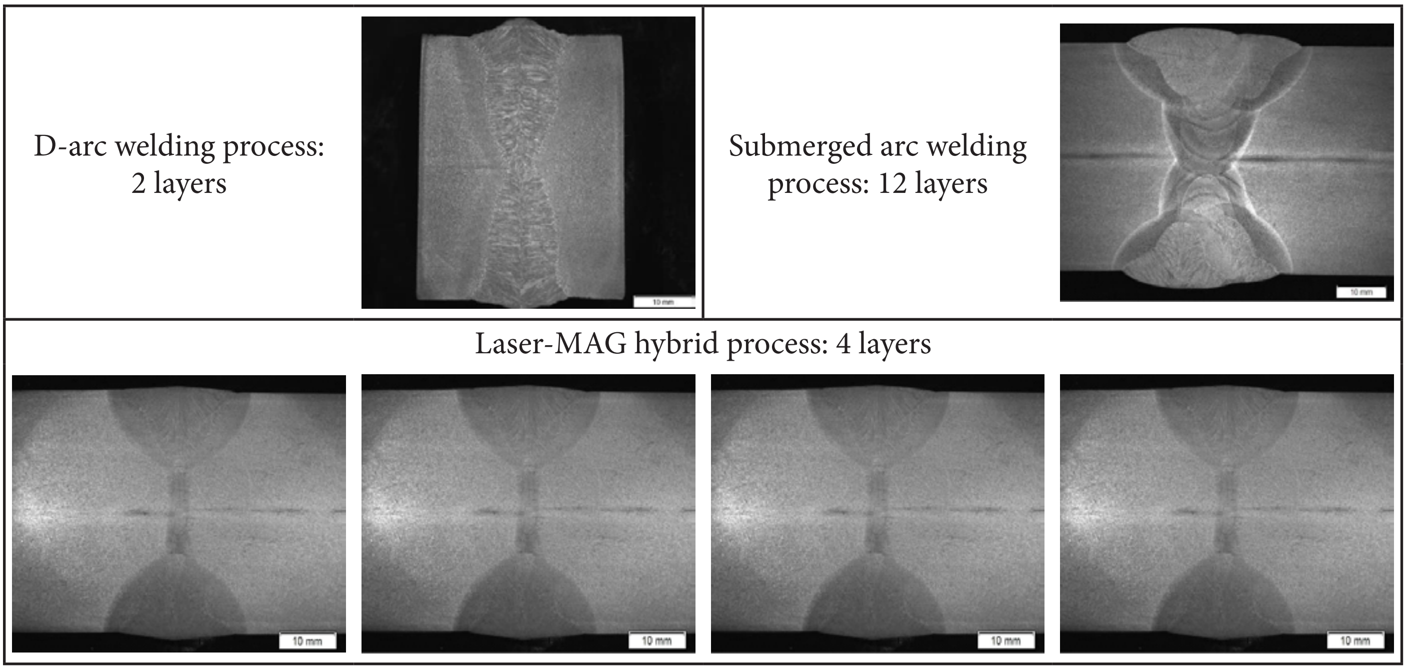

Fig. 9. Comparison of high-performance welding processes

Summary

The article discusses properties of various welding power sources and their effect on penetration depth. Particular attention was paid to the comparison of cutting-edge high-power technological lasers used separately or combined with the MAG welding process (in the hybrid variant). Another laser application is laser welding in the vacuum, enabling the obtainment of weld properties very similar to those obtainable using the electron beam welding process. The author's tests performed in the 1990s and involving the use of low-power lasers revealed that it was possible to double the depth of penetration. The foregoing was confirmed by results of latest tests involving the use of high-power lasers and performed at institutes in Rostock and Aachen.

Figure 9 presents the overview of welding possibilities, where the submerged arc welding process can be perceived as a fully established method, usable for comparative purposes.

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