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Electron Beam Use in Welding and Allied Technologies

Abstract: The article discusses the use of an electron beam in welding engineering, presents examples of electron beam utilisation in industry taking into consideration welding, fast prototyping and surface texturisation, provides information on techniques which can be used during welding as well as indicates practical application areas and advantages of the technology.

Keywords: electron beam welding, welding, fast prototyping,surface texturisation

Introduction

Despite widely used arc welding and laser beam welding technologies, electron beam welding remains commonly applied in the automotive industry, machine building industry, electronics, electrical industry and aviation (Fig. 1). EBW technology enables the obtainment of high quality joints of all weldable structural metals. Particularly advantageous joint properties, similar to those representing the parent metal, are achieved during high vacuum electron beam welding of steels, magnesium alloys, aluminium, copper, nickel and zircon. The market offer includes universal and specialised tools also for welding in a partial vacuum [1-6].

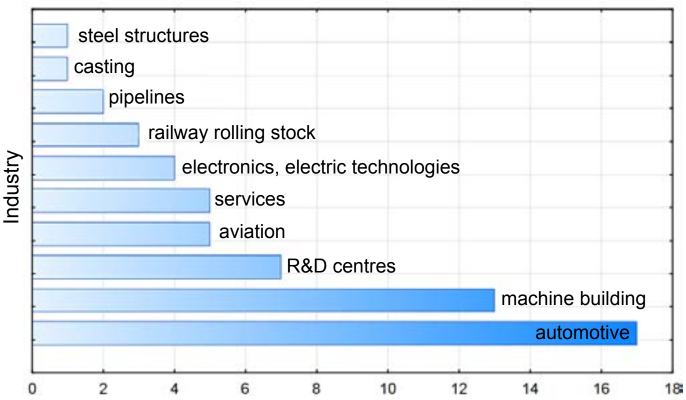

Fig. 1. EWB application areas [1]

The use of electron beam as a welding heat source offers new possibilities, absent in arc or even laser methods. Among others, electron beam welding is characterised by the following [7]:

- the zone of interaction with a material is characterised by a very high power density between 10 and 100 kW/mm2. In this respect the concentrated electron beam considerably outperforms other power sources used in welding processes. Only the laser beam, to a limited extent, is characterised by similar power density values;
- electron beam welding is practically adiabatic in character. The lack of thermal energy transmission to the environment is responsible for a limited heat affected zone, which is frequently highly desirable in order to maintain the parent metal microstructure and weld mechanical properties. This results in the lack of greater problems during welding metals of high heat conduction such as copper, aluminium, silver, gold etc.;
- the electron beam is easy to control. The electron beam energy parameters can be controlled, practically in an inertia-free manner, within the whole range from minimum

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to maximum values. Also, the spatial and time-related beam structure can be shaped very precisely in accordance with the welding process requirements. The electron beam is easy to move and deflect. This enables the precise control of the beam along the welded joint having a complicated profile and enables the oscillatory movements of the beam for technological purposes;

- electron beam welding of metals is accompanied by numerous physical phenomena indicating the process status. The best known phenomena include secondary electron emission, which, among others, depends on the workpiece surface condition, momentary duct depth during key-hole welding, content of impurities in materials to be welded and power density distribution in the beam;
- electron beam welding is usually performed in a vacuum, which enables welding reactive metals such as beryllium (material used for fuel element shields in nuclear reactors), niobium, vanadium, titanium, tantalum and their alloys;
- the electron beam welding process can be fully automated, which is of particular importance when the welding machine is an element of an automated production line. It is important for automated systems to be equipped with databases and expert systems enabling the obtainment of, among others, welded joints satisfying the most restrictive quality requirements.

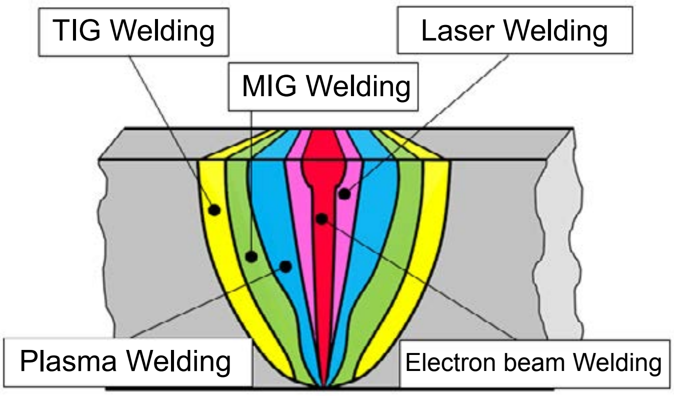

Fig. 2. Geometry of a butt joint made using various welding technologies [8]

The different, heat source-dependent manner of heating workpieces is decisive for the shape and dimensions of welds. Figure 2 presents the comparison of a butt weld made using various welding technologies. The small heat input and narrow weld cause electron beam welding to be accompanied by small workpiece deformations. The absence of deformations eliminates the necessity of post-weld finishing.

The amount of heat necessary for melting weld metal and heat losses in the welding process define the total amount of heat which must be supplied by the heat source in order to make a weld. As regards welding process-accompanying heat losses, the electron beam has a significant advantage over other heat sources. While comparing laser beam and electron beam welding processes, it is possible to assume that for solid-state lasers approximately 4% (Nd:YAG) and 25÷50% (fibre and disc lasers) of the energy supplied is used in the welding process. The efficiency of electron-beam based devices is between 60 and 70% [7]. The primary heat amount-affecting factors include the thermal energy concentration degree and the welding rate. Electron beam welding is characterised by more than 10-times better energy utilisation than mechanised arc welding. During arc welding, already at the stage of energy (heat) transfer from the arc to the workpiece, significant (approximately 15%) energy losses due to radiation and convection are observed. Considerable losses, i.e. 15÷20%, can be ascribed to the heat used for electrode coating or flux melting and evaporation. In addition, in cases of low welding rates, a significant amount of heat is lost for heating workpieces in heat conduction. Therefore, in comparison with arc welding processes, electron beam welding is characterised by very high thermal efficiency. However, while considering the general electron beam welding energy balance it is necessary to take into consideration energy used for driving vacuum pumps. Although this will reduce the thermal efficiency factor, it will still be significantly higher than that characterising other welding methods, particularly if welding in a partial vacuum is taken into consideration [7].

Applications of Electron Beam Technologies

The primary advantage of electron beam welding is the possibility of making the most difficult material connections and welded joints in very thick structures or in places impossible to access using other welding methods. In addition, new devices make it possible to weld elements of very small thicknesses (in micrometres) at a very high rate. It should be also noted that EBW is the only technology which allows making joints of materials having very different physico-chemical properties without the necessity of using buffer (intermediate) layers or making joints of poorly weldable materials using arc methods, e.g. 2000 series aluminium alloys [9] or Allvac 718 Plus nickel alloys [10]. EBW technology enables making welds in poorly accessible places or making very narrow welds with a significantly limited HAZ and minimum welded joint deformations as well as joining materials without edge bevelling and, in most cases, without filler metals. In numerous cases EBW remains the only applicable technology and even the latest generation laser welding devices are incapable of replacing electron beam welding [11], e.g. welding of stator elements (Fig. 3).

It should be mentioned that modern devices enable conducting electron beam welding with one beam or with many beams almost at the same time (a beam of a high frequency, higher than the human eye can spot, is activated and deflected, which in consequence creates the “presence” of many beams), e.g. in welding toothed wheels or particulates filters [11]. Multiple-beam welding is used, among others, in welding with pre-heating (e.g. when cold crack avoidance is important) (Fig. 4a), or in post-weld heat treatment processes (in order to eliminate brittle quenched microstructures such as martensite) (Fig. 4b) or for welding “accompanied by” pre-heating or post-weld heat treatment (Fig. 4c). Multiple electron beam welding, i.e. utilising several programmed-shape beams is also used in order to reduce welding stresses while welding (Fig. 5).

The major advantage of electron beam welding is the possibility of making welded joints without a filler metal, yet in some applications the use of the filler metal

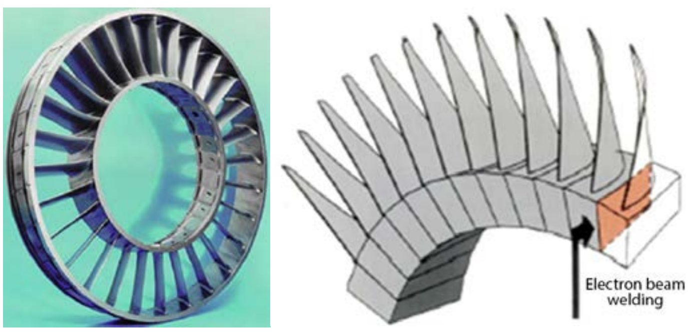

Fig. 3. Example of unique EBW application, i.e. welding of stator elements [12]

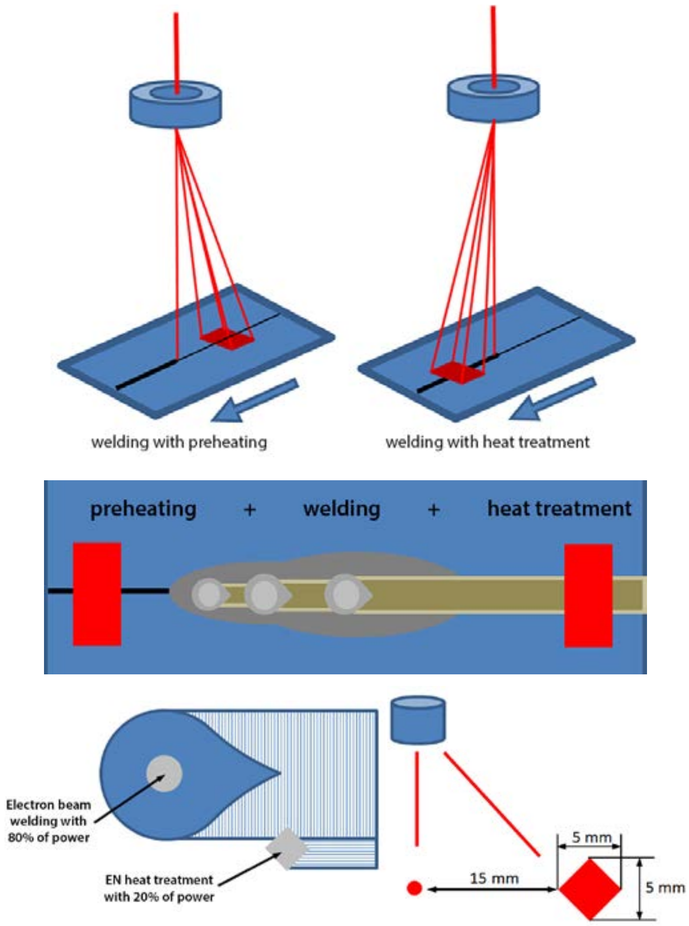

Fig. 4. Electron beam welding process a) with preheating or post-weld heat treatment, b) with preheating and post-weld heat treatment, c) with heat treatment conducted outside the weld axis d) exemplary geometrical dimensions of the additional beam [13, 14]. EB – electron beam

improves technological possibilities, which requires the device to be equipped with a filler metal wire feeding system. Such is the case, for instance, with welding cast iron with unalloyed steel (filler metal decreases hardness and prevents the formation of hardening cracks in the joint) or with welding duplex steels in order to ensure the appropriate chemical composition of the weld and, in consequence, corrosion resistance [11]. The filler metal is also used for fast prototyping [16], overlay welding and element repair [17]. The process of overlay welding is usually performed using a filler metal in the form of a wire or a strip. The filler metal is used for applying expensive abrasion-resistant layers, e.g. stellite materials [11].

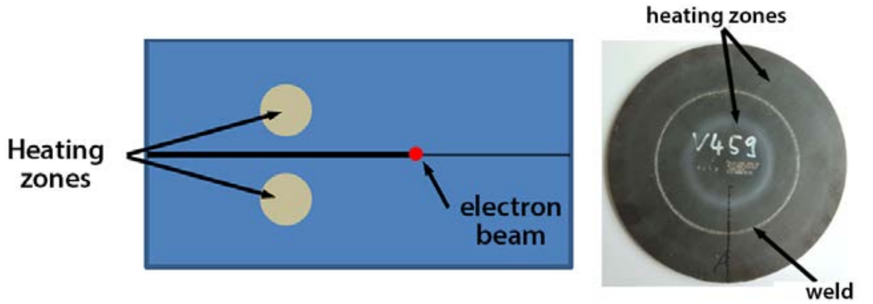

Fig. 5. Examples of additional electron beam uses in reducing welding stresses; arrangement of beams while making a) linear welds, b) all-round welds [15]


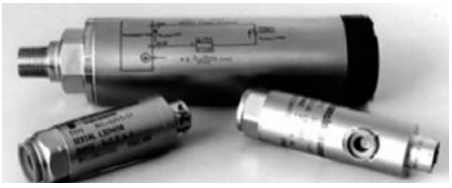

Fig. 6. Examples of electron beam welded elements: battery casings, aneroid barometers, relays, contactors and compensating capsules [18]

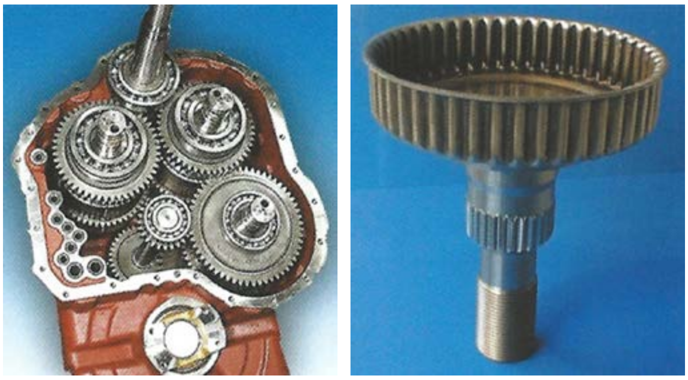

Fig. 7. Electron beam welding of toothed gear elements [19]

Electron beam welding is used in electronic and electrical industries for welding small-sized elements (Fig. 6) such as battery casings, aneroid barometers, relays, contactors and compensating capsules. Devices having an accelerating voltage of 60kV enable the efficient welding of strain-free critical joints characterised by very high and repeatable quality [18].


Fig. 8. Electron beam welding of supercharger shafts a) device, b) element after welding [18]

In the automotive industry, electron beam welding is usually used for making toothed gear elements (Fig. 7) and turbocompressor shafts (Fig. 8). Making an entire shaft (Fig. 8b) lasts approximately 15 seconds.

Electron beam welding is also used in the production of wind tower elements [20, 21]. Figure 9 shows the presently used solution, i.e. submerged arc welding and the new solution, i.e. welding using the electron beam (Non

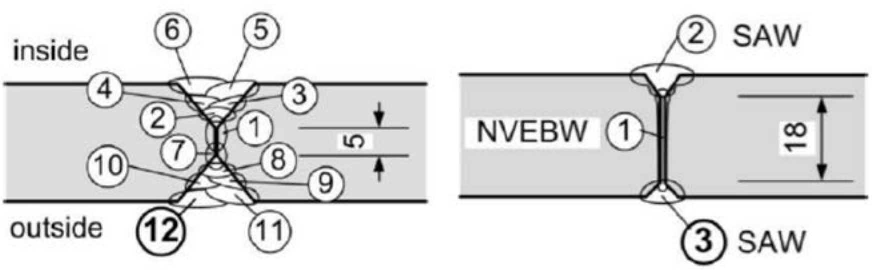

Fig. 9. Electron beam welding of wind tower elements a) presently used solution - submerged arc welding, b) welding using the electron beam and submerged arc, joint thickness: 30 mm, steel: S355J2+N [20]

Vacuum Electron Beam Welding - NVEBW) and submerged arc. The combination of both technologies enables the reduction of welding costs and welding strains [20]. Vacuum welding is used in the production of rotor caps (Fig. 10).

Figures 11 and 12 present the examples of using electron beams for producing machinery elements. The use of EBW enabled the reduction of costs related to the production of transport hook slings and hydraulic servomotors.

Fig. 10. Electron beam welding of a wind tower element – rotor cap [21]

Fig. 11. Electron beam welding of transport hooks made of high-strength steel [19]

Fig. 12. Electron beam welding of hydraulic servomotor elements (force 15000 kN), penetration depth of 95 mm [19]

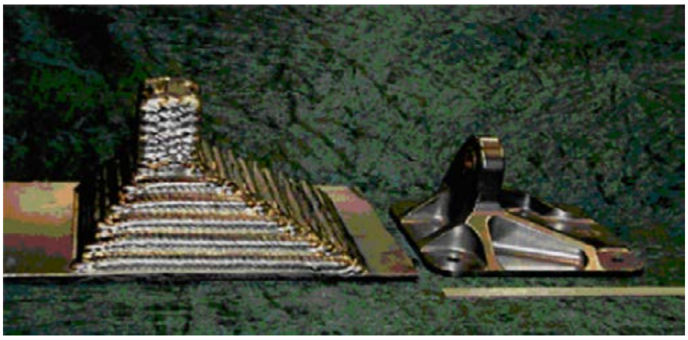

Fig. 13. Example of the electron beam use for fast prototyping [18]

Fast prototyping (creating objects without using traditional material processing technologies) utilising electron technologies (electron beam direct manufacturing – EBDM) is applied for producing single elements (Fig. 13), prototypes or models as well as short series which would be excessively expensive if produced with other technologies, e.g. by casting or forging. The essence of the process is the possibility of fast prototyping using powder [22], the individual fractions of which are exposed to the electron beam thus making it possible to make an object of a pre-defined shape. Precise control combined with

Fig. 14. Example of the electron beam use for fast prototyping of endoprosthesis elements [22]

a wide material range and the fact that the process is performed in a vacuum, prevents oxidation and hydriding of a material being molten. This technology is used, among others, in the production of endoprosthesis elements (Fig. 14) or turbine rotor blades.

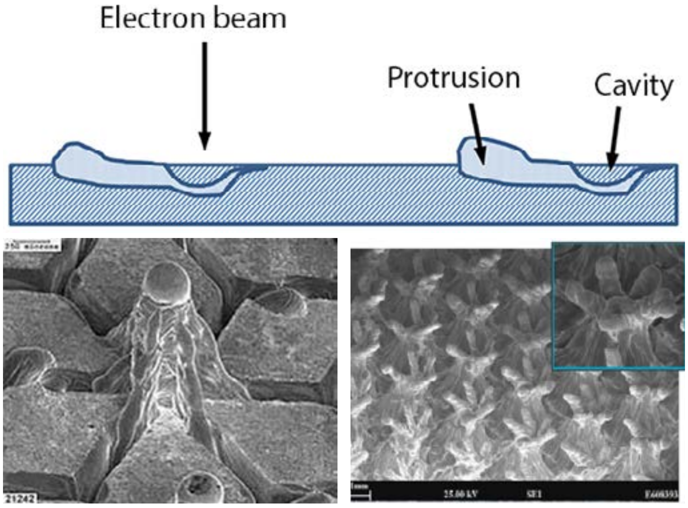

Fig. 15. Examples of the electron beam use for surface texturisation, a) process scheme, b) single protrusion, c) and d) surface after texturisation [18]

Fig. 16. Examples of electron beam use for surface texturisation, a) structural elements used in the aviation industry, b) endoprosthesis after surface texturisation c) surface after endoprosthesis surface texturisation, d) fragment of a drive shaft after texturisation [18]

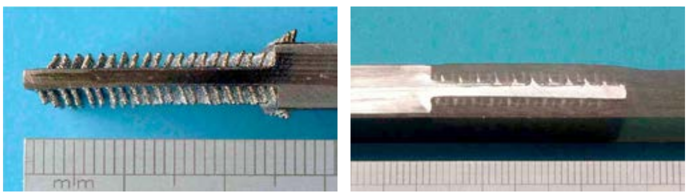

Fig. 17. Exemplary electron beam use for surface texturisation while joining metals with plastics, Surfi-sculpt™ technology by Comeld [18]

It should be emphasized that electron technologies enable surface texturisation (Fig. 15-17). This process consists in the formation of characteristic surface micro-convexities (Fig. 15) and is used, among others, in medicine for improving biocompatibility (Fig. 16) and in the machine-building industry, e.g. for joining metals with plastics (Fig. 17).

Summary

Electron beam welding is used in high-volume, series and unitary production. It enables making joints of a vast range of structural materials and allows producing both miniature and large-sized elements. In many applications electron beam welding is competitive for arc and electron beam welding. EBW enables the reduction of finished element production costs and the use of less complicated structural solutions. If it is not possible to perform welding in a vacuum, welding in a partial vacuum or without a vacuum can be conducted. It should be emphasized that the electron beam is used, among others, for quick prototyping, surface texturisation and overlay welding.

While describing only some possibilities connected with the use of electron beams in welding engineering and widely defined material engineering, it should be emphasized that modern devices using a voltage of 150 kV do not require special additional external screens protecting against X-radiation, are entirely safe and satisfy the strictest safe operation-related requirements.

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