FIELDS OF APPLICATION OF MAGNETIC-PULSE WELDING (REVIEW)

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The review considers the main directions of investigation of magnetic-pulse welding. Weldability of the combined welded joints is evaluated, and fields of application of this process are given.

Keywords: *magnetic-pulse welding, directions of investigations, tubular products, equipment, weldability, fields of application of magnetic-pulse welding*

Magnetic-pulse welding (MPW) is used in industry in a course of several decades and its place in modern industrial production and tendencies of realization are to be determined and evaluated.

Monitoring of dynamics of publications (electronic documents in preference) with fetching by years and filtration on key word combination in a text was carried out for quality evaluation of tendencies (trend) of scientific-and-practical activity of the investigations and MPW application at present stage. Such current search systems as PdfQueen, FreePatentsOnline, Google-Scholar (Google Academy), Scirius, 2dix, PdfSearch, etc. (Figure 1) were used at that.

Google Scholar system having functions of fetching by years and filtration on exact word combination was applied as a main search system. It should be noted that many companies are not tend to put data on manufacturing peculiarities of release of their products, including MPW application, in open publishers. In this connection searching in this direction is complicated and indirect methods are to be used for analysis and opinion of experts should be relied on.

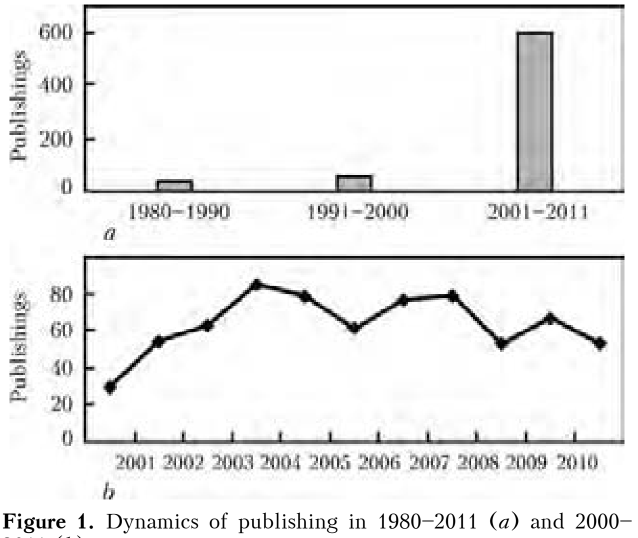

Figure 1. Dynamics of publishing in 1980–2011 (*a*) and 2000–2011 (*b*)

Number of educational centers in developed countries (University of Waterloo, Technische Universitat Dortmund, Fraunhofer Institute for Materials and Beam Technology IWS, Ohio State University, Wuhan University of Technology, Osaka University, Tokyo Metropolitan College of Technology, Belgian Welding Institute, etc.) [1–6] deal with the theoretical issues of MPW, and research groups of many leading automakers and airspace companies (PST, DANA, PULSAR, MAXWELL MAGNEFORM, etc.) work in the field of industrial development and implementation.

Investigations of theory and practical application of MPW have been carried out during decades in CIS countries immediately after its development in the USSR [7–9]. Number of publications on this theme against a background of increase is relatively small and number of publications on practical application of MPW is still smaller. Obviously, this is concerned with general condition of economy in these countries.

E.O. Paton Electric Welding Institute, Kharkov Polytechnic Institute, M.V. Khrunichev State Research-and-Production Space Center, Don Polytechnic Institute, Samara State Aerospace University with Samara Center of MPTM and etc. are the main centers of scientific-and-practical activity in the field of magnetic-pulse treatment of metals and MPW in CIS countries.

MPW is mainly used for joining of tubular products in the world practice. Welding of sheet products is yet mainly at the stage of research workup.

The main obstacle for MPW implementation is, apparently, a relative high cost of equipment, i.e. initial price of the unit makes from 100 thou USD, regardless all safety of modern equipment for MPW (inductors can carry up to 2 mln of pulses) and its high efficiency (minimum 6 welding pulses per minute; limitation is a time of process of loading/unloading of parts).

Another restriction is a necessity of application of advanced safety measures (high voltage, strong magnetic fields, danger of inductor breakdown) which require significant investments in addition. However, this problem can be brought to absolute minimum [10] in process of robotization and automation.

Table of weldability of tubular parts using MPW method

Outside pipe	Inside pipe												
	Al series 1000	Al series 3000	Al series 5000	Al series 6000	Al series 7000	Cast aluminum	Copper	Bronze	Carbon steel	Stainless steel	Nickel	Magne-sium	Tita-nium
Al series 1000	+	+	+	+	+	+	+	+	+	+	−	+	−
Al series 3000	+	+	+	+	+	+	+	+	+	+	−	−	−
Al series 5000	+	+	+	+	+	+	+	+	+	+	−	+	−
Al series 6000	+	+	+	+	+	+	+	+	+	+	−	+	−
Al series 7000	−	+	+	+	+	+	+	+	+	+	−	−	−
Cast aluminum	−	−	−	−	−	−	−	−	−	−	−	−	−
Copper	−	−	−	−	−	+	+	+	+	+	−	−	−
Bronze	−	−	−	−	−	+	−	−	+	−	−	−	−
Carbon steel	−	−	−	−	−	−	−	−	+	+	−	−	−
Stainless steel	−	−	−	−	−	−	−	−	−	+	−	−	−
Nickel	−	−	−	−	−	−	−	−	+	−	+	−	+

Note. «+» means weldability of combination of materials, «−» absence of weldability.

Probably, MPW will become more available in the foreseeable future as the progress in the filed of pulse energy storages continue (in this case special high-voltage pulse capacitor) and their production cost reduces (the price makes more than half of the cost of all MPW equipment). This is highly possible since significant scientific-and-practical and financial resources are concentrated in the field of applied physics and military-industrial complex at present time. These resources are directed on development of mobile systems of electromagnetic damaging, mobile electromagnetic guns (railotrons) and lasers in which high-voltage capacitor energy storage is one of the main energy components. Therefore, more effective capacitor systems can appear soon in civil fields of industry that allows developing available stationary or even mobile systems of MPW.

Such joints as aluminum–aluminum, aluminum–copper, aluminum–magnesium, aluminum–titanium, copper–copper, copper–steel, copper–bronze, nickel–titanium, nickel–nickel, steel–steel are made at present time in industry using MPW. Table of weldability, given in study [11], is recommended to use for tubular parts.

First of all for automakers are interested in practical application of MPW. Therefore, independent companies on development and implementation of magnetic-pulse techniques and technologies (DANA, PULSAR, PST, MAGNEFORM, etc.) direct the majority of their developments toward this sector. Respectively, manufacturers of MPW equipment get significant part of their profit exactly from automaker sector of industry.

Possibility of welding of dissimilar metals as well as simplicity of the process, high level of automation, absence of thermal deformations, good quality of welding and reproducibility of results, elimination of cleaning and usage of consumables (welding wire, gases), absence of necessity in local exhaust ventilation due to lack of harmful emissions, extremely low percent of rejects and etc. [12] attract the manufacturers in this case first of all.

Application of MPW in the motor car construction is relatively small in comparison with other technologies, but has stable tendency to growth. Experts claim that MPW has significant potential and real mass expansion [13] is foreseen in the nearest years.

Technology and equipment for MPW created by DANA (Dana Holding Group) Corporation, being the largest manufacturer and supplier of assemblies and parts for automobile market, are developed mainly for own needs of the company in contrast to «pure» companies-developers (PULSAR, PST, etc.). One of the six subdivisions of the company (Spicer Driveshaft) specializes on manufacture of main shafts including by MPW (Figure 2). Wide implementation of MPW according to assessment of DANA specialists allows creating the lightweight frames and other elements of automobile structures from dissimilar metals that result in 70 % weight decrease and 10 % reduction of fuel consumption. This, in turn, cut down harmful emissions in atmosphere including during manufacture of automobiles («green technology») [14].

Schweisstec Exhibition taken place in Stuttgart became a prominent event for motor car construction in whole and MPW, in particular. First in the world

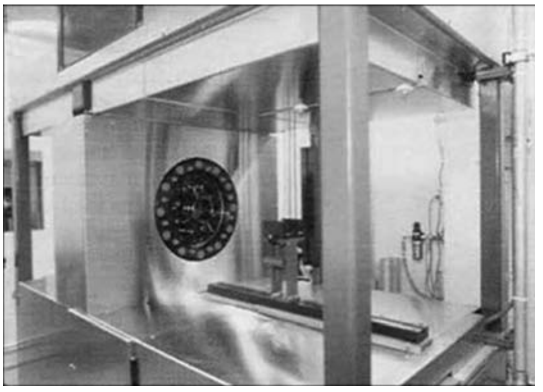

Figure 2. MPW unit at «Spicer Driveshaft» plant

lightweight frame of body of passenger car consisting of high-strength aluminum, steel and copper elements, wholly welded using MPW (Figure 3) [15], was presented by PST company (PST Products GmbH) on the Exhibition.

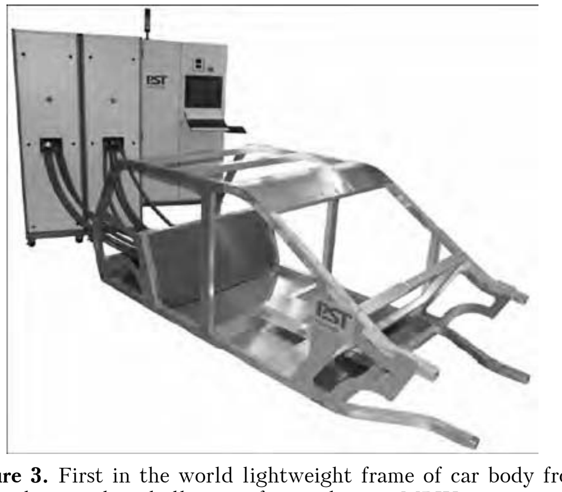

Figure 3. First in the world lightweight frame of car body from dissimilar metals, wholly manufactured using MPW

Developers outline the following advantages of the technology at that:

- complete absence of thermal deformations;
- welding of dissimilar metals (aluminum–steel, aluminum–copper);
- 35 μs duration of welding pulse;
- possibility of performance of straight-line welded joints of up to 3 m length.

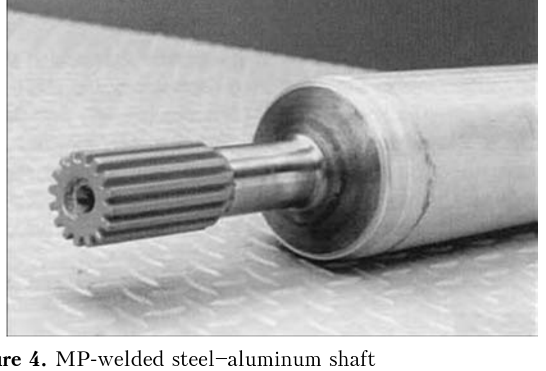

Figure 4. MP-welded steel–aluminum shaft

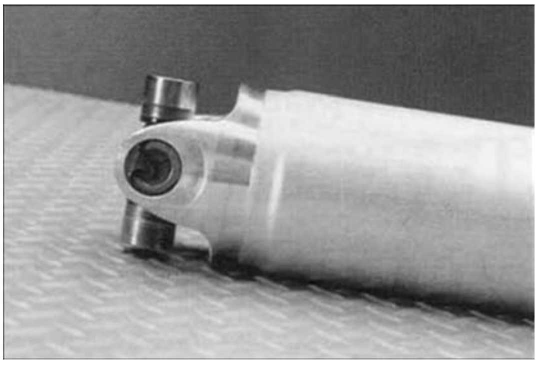

Figure 5. Aluminum (Al–Al) shaft

Vector of development of assembly technology lying in maximum possible replacement of all methods of fusion welding by MPW process as well as vector of investments in the nearest future are determined here as a matter of fact. In turn, this can indicate a direction for investigations and developments.

A list of some automobile assemblies and parts being manufactured using MPW (Figures 4–11) is given below [13, 16–18], i.e. shock-absorbers (aluminum or steel); elements of suspension (dissimilar metals); components of chassis; block elements; safety crash-boxes; elements of automobile air-conditioners; high-pressure gas vessels; oil filters; elements of main shaft; elements of lightweight seats; elements of fuel pipes, joints of frame elements; elements of exhaust systems [15].

Manufacture of aluminum–steel main shafts with the help of MPW allows significantly reducing their weight. At that noticeable increase of efficiency, improvement of ecology, reduction of wastes and rejects virtually to zero are observed [12].

PULSAR (Pulsar Ltd.) claims that they have invested more than 100 man-years in the development and industrial finishing of MPW. Now the company starts impetuous implementation of this technology all over the world. Thus, recent implementation of Pulsar MPW 25 unit on an assembly line of receiver-dryers of automobile air conditioners at the plant of famous manufacturer of car components (TI Automo-

Figure 6. Receiver of car air-conditioner

Figure 7. Fragment of cross-section of copper-aluminum joint 25 mm in diameter

tive Company) allows replacing nonconsumable electrode welding and reaching efficiency of 1000 assemblies per shift as well as increasing quality of parts and reducing percent of reject (Figures 7 and 8) [19].

Application of MPW method in assembly of bodies

Figure 8. Aluminum ring MP-welded to steel bolt

of fuel elements (fuel slugs) for the needs of nuclear power engineering is still under investigation. Undoubtedly, it will find wide application (Figure 11). This technology is more preferable in series of cases than others [20]. High quality and reproducibility of results, simplicity, absence of direct contact with clad surface of body appearance of new materials for bodies (from list of clad ferrite-martensitic and oxide dispersion-strengthened steels) accompany this process [21, 22].

Constantly increasing demand in permanent joints of parts from dissimilar materials exists in the airspace field. MPW is an ideal method for joining of such dissimilar metals as titanium–nickel. Brazing or non-

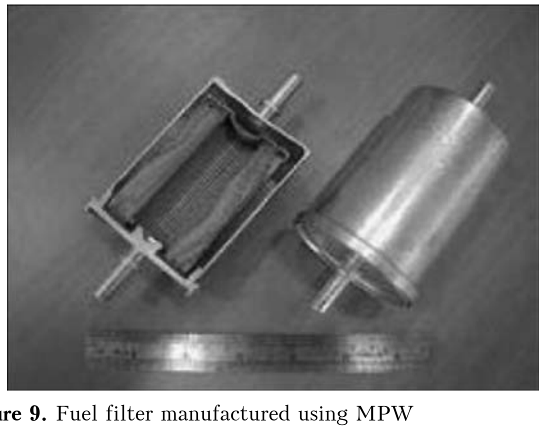

Figure 9. Fuel filter manufactured using MPW

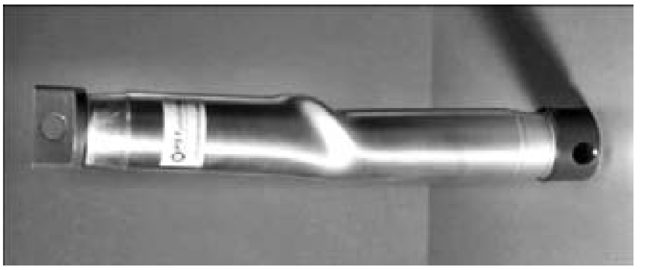

Figure 10. Sample of MP-welded main shaft (aluminum–steel) after successful strength tests in torsion

consumable electrode welding [10] is used at present time in manufacture of the fuel pipes for airspace designation. Boeing Company, in particular, applies MPW for manufacture of high-pressure pipeline accessories (hydraulics) [23].

Process of MPW of tubular structures with preforming (joint development with Dneprodzerzhinsk

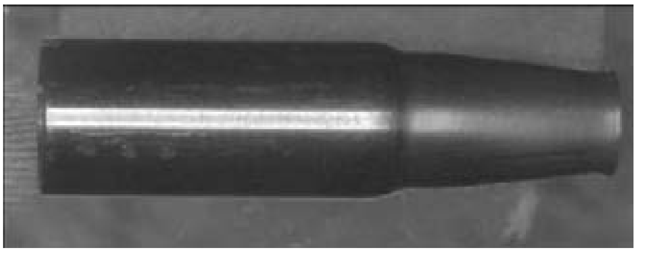

Figure 11. Fragment of sample of MP-welded fuel slug

State Technical Universiry) [24] is implemented at M.V. Khrunichev SRPSC. A new method of obtaining of stamped-welded closed structures from thin sheet materials (lightweight bodies of electric couplers) using magnetic-pulse technology was developed and implemented at the same place. Developers named it as resistant MPW with simultaneous heating of joint by induced currents and effect of pulse magnetic pressure, i.e. combination of MPW and resistance welding [25].

Impact-pulse method of welding was recognized the best for development of superconductor key with

Figure 12. Magnetic-pulse cutting (punching) of parts of automobile designation using elements of PST equipment in Fraunhofer IWU [28]

heat control in a form of Cu–Al–Cu sandwich for the needs of cryogenic technologies. Such a key characterizes by low heat contact resistance that makes MPW application highly perspective [26]. Positive practical results in welding of films on the basis of amorphous nickel («metallic glass») useful for the needs of manufacture of micro instrument with unique properties [27] were obtained with this method.

New process of magnetic-pulse punching (Figure 12) related to MPW and developed by the specialists of Fraunhofer Institute for Machine Tools and Forming Technology (Germany) is at the stage of finishing and pre-industrial implementation. Its difference lies in absence of wear-out of mechanical tool and extremely high speed of punching, i.e. 0.2 s (this operation is performed for 1.4 s with the help of laser technologies). This project is financed by Volkswagen Company [28].

Obtaining of joints by means of magnetic-pulse crimping and some other magnetic-pulse technologies can be referred to MPW related technologies.

CONCLUSIONS

1. MPW and related technologies are efficient and constantly developing technologies with high research and practical potential requiring further research and design efforts.

2. Field of MPW application will grow in appearance of new materials.

3. Rise of technical and economic indices of equipment in particular due to reduction of its cost and increase of life time of elements will promote interest to MPW.

4. Technological aspects of MPW (improvement of weldability of existing materials, reduction of power-consumption of the process) as well as engineering developments for improvement of tools (for example, special types of inductors, etc.) become the object of investigation and development.

5. Some fields of industry are ready for mass implementation of MPW expecting in the next years.

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