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A review on the effect of magnetic field on weld quality & weld geometry in arc welding

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Abstract

External magnetic field (EMF) nowadays is widely used in application of arc welding because of its positive effects on weld quality and weld geometry. The presence of EMF during arc welding lowers the value of sensitization of metal near the heated area resulting in resistance to localized corrosion. This resistance to corrosion is caused mainly due to Cr redistribution in base metal due to externally applied magnetic field. The applied EMF deflects the welding arc by electromagnetic force and applies force on electrons and ions within the arc which causes arc to deflect away from the normal path. Further, the welding arc can be made to deflect backward, forward or sideways with reference to welding direction and electrode depending upon the direction of applied magnetic field. In this article, results of various different experiments performed by taking different welding parameters are studied which would contribute in improvement of weld quality as well as weld geometry.

Keywords: external magnetic field, arc welding, corrosion resistance, weld bead geometry, arc instability

Introduction

Welding can be defined as a process of joining two materials of same fundamental type or class in which these materials are joined by formation of a chemical bond under combined action of heat and pressure. Thus, process of welding involves fusion of two or more metal pieces together by making use of heat energy produced from welding kit.In case of arc welding, an arc is struck in between the electrode and metal, as a result of which a huge amount is heat is generated which causes base metal to melt as well as filler metal. The electrode is now removed after melting point of metals is reached, breaking the arc between metal and electrode allowing the molten weld pool to freeze or solidify in still air. Now with the increase in demand of high quality welded joints for high quality products, the efficiency of welded joints formed by arc welding had to be increased and this aim was achieved by the use of externally applied magnetic field during the welding process. Experimentally it was noted that externally applied magnetic field during arc welding exerts a force on electrons and ions present inside the arc and this causes arc to be deflected away from its normal path, also arc produced can be deflected in forward, backward or sideways direction by applying magnetic field in a suitable direction relative to the direction of motion of electrode.

One of the biggest draw-back of traditional arc welding is the formation of spatter during operation, resulting in more time and fuel consumption. This problem was overcome by making a use of Cusp type external magnetic field [19] which changes cross section of arc plasma from conventional circular shape to elliptical shape resulting in better bead performance. Further by using external magnetic field of optimum intensity, the welding speed also increases resulting in undercut free and no porosity welds are formed. It is also known that amount of arc deflection depends upon the intensity of magnetic field, arc current and arc length also [25] .The Presence of magnetic field increases fine grain-structure which further enhances mechanical properties such as improvement in low temperature, solidification crack susceptibility, corrosive resistance, formability and reduces the effect of segregation scale [24]. The process of arc welding done in absence of magnetic field makes the joint more susceptible to localized corrosion in heat affected zone but resistance to this corrosion is provided by making use of external magnetic field which causes chromium redistribution in the base metal resulting in better corrosion prevention, also resulting in better grain structure [30]. Therefore external magnetic field used in case of arc welding results in better weld geometry as well as better weld quality.

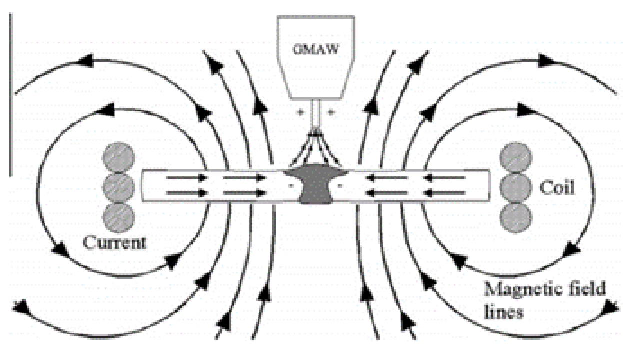

Fig 1: Schematic of the experimental setup to induce an external magnetic field during welding.

Literature Review

Numerous investigations have been done by the researchers reflecting the effect of external magnetic field in the presence of arc welding on weld bead geometry, grain structure of base metal, corrosion resistance, tensile strength, toughness, welding defects, spatter, weld penetration and weld appearance and the summary of their work has been discussed.

A.P. Ehiasarian, *et al.* [15] found that with Increase in movement of molten metal there is an increase in the diameter of nugget, HAZ of the welds are softer as compared with that of welds accomplished conventionally. Also the refined grain structure and increase in nugget diameter is seen with use of

EMF along with improvement in tensile strength of joint. Also for low welding current with long welding time makes effect of EMF more efficient and effect of EMF is ignored when there is high welding current or long welding time, which makes nugget fully grow without using EMF. André Anders, Et.al [13] abstracted Ion flux from vacuum arc cathode spots in the absence and presence of a magnetic field on welding performance by using 3 kinds of the welding currents 7.8 KA, 8.0 KA and 8.5 KA and reflected that the grain structure was refined and there is an increment in the diameter of the weld nugget. Weld performance was positively affected by change in the magnitude of the welding current. Qi Shen and Yong Bing Li *et al.* [22] studied the effect of external constant magnetic field on weld nugget of Resistance spot welded dual phase steel DP590 and found that the weld nugget diameter increases under the effect of the external magnetic field. Weld appearance, weld quality, grain structure and the mechanical properties were improved at welding current 9.0 KA. Cicero M.D. Starling and Paulo V. Marques *et al.* [8] abstracted Statistical modeling of narrow gap GTA welding with Magnetic arc oscillation and found that the bead shape was improved under the oscillation and the lateral fusion of the joint is not affected. The welding current is kept on the range from 200A to 250A and a gap width of 7mm to 9mm. A. Zhainakov and T.E. Urusova *et al.* [23] examined the numerical simulation of gas dynamic flows formed by an electric arc in an external transverse magnetic field and it was found that a stronger deformation of the arc is caused by an intense gas dynamic flow. The welding current with corresponding values of 50, 75, 100 and 150 A was used.

Gatzen [14] has investigated through the Influence of low-frequency magnetic fields during laser beam welding of aluminum with filler wire that the magnetic fields are often used to steer the arc cathode spot on the cathode surface to minimize the generation of droplets further the magnitude and the composition of the ion flux can be controlled by the steering magnetic field in the cathodic arc evaporation. Yang Li *et al.* [17] projected the effect of external magnetic field on resistance spot welds of aluminum alloy and observed that Magnetic flux density around the weld is used for reconstruction of current and the density of current is low at middle and high at edges of nugget and current density distribution can tell whether weld nugget is formed or splashed. No effect on RSW process with aluminum alloy can be seen with long welding time. Rong Chen and Wang *et al.* [29] investigated the effect of axial magnetic field of laser beam welding of stainless steel to aluminum alloy and found that the magnetic field would reduce cracks, stabilize the weld.

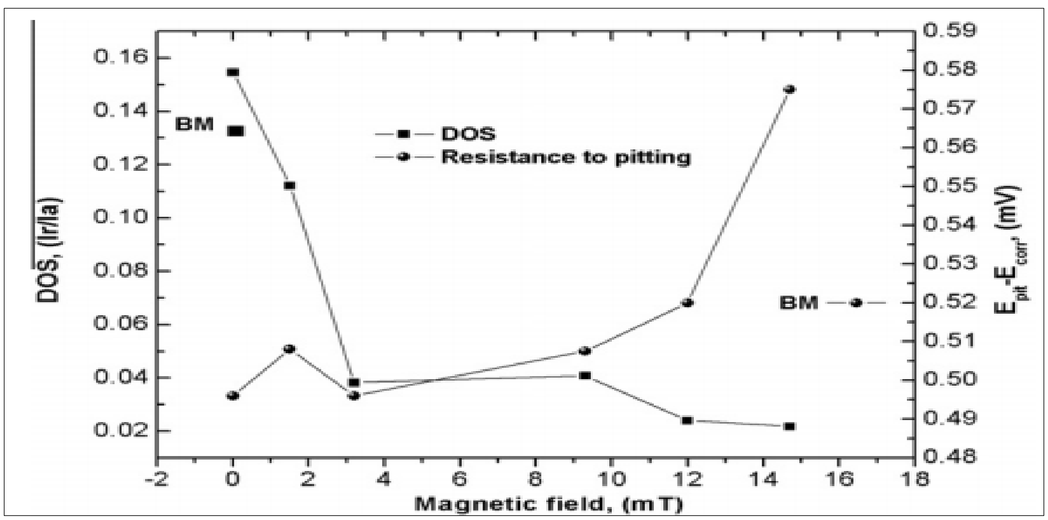

Fig 2: Degree of sensitization and resistance to pitting corrosion as a function of the intensity of the magnetic field applied during welding

M.Malinowski-Brodnicka and W.J.P. VINK *et al.* [35] studied the effect of electromagnetic Stirring on GTA welds in austenite stainless steel and found that a symmetrical weld bead is produced. The magnetic field density increased from 0 to 5 mT increases the width of the weld bead. With the increase in the magnetic field strength the grain refining effect increases. The weld pool becomes skewed with the application of the constant axial magnetic field. Y. B. Li, Q. Shen, *et al.* [16] studied the Quality improvement in resistance spot weld of advanced high strength steel using external magnetic field and predicted that when EMF is applied axially then the change in microstructure and tensile property of weld can be observed. Stronger weld joints are formed under EMF frequency from 0 to 5 Hz. With increase in further welding current, the strength of weld increases also the weld joint with EMF has higher tensile shear force compared to that of weld joint without EMF. Observation of promotion of growth of Aluminum and Iron (Al/Fe) IMC layer during weld is seen and diffusion of Fe to weld ceases and Si particles in IMC layer increases which further controls the growth of brittle Al/Fe IMC layer. Yibo Liu, Qingjie Sun, *et al.* [18] have studied the effect of axial external magnetic field on cold metal transfer welds of aluminum alloy and stainless steel and researched that in absence of magnetic field, plasma expansion shows higher ion energy for higher charge states while taking magnetic field in consideration, it resulted in a broader distribution and increased ion energies. Charge state is approximately proportional to the ion energy and film microstructure and its properties are affected. Qi Shen, YongBing Li, *et al.* [10] through the impact of External Magnetic Field on Weld Quality of Resistance Spot Welding proved that the flux density is used for determining the strength of the magnetic volume force. To determine the spatial distribution of the elements the most important parameters, frequency and flux density are kept at 25 Hz and 250 mT respectively.

K. Nomura, K. Morisaki, *et al.* [19] found that by using cusp-type magnet device the cross section of arc changes from a circular shape to an elliptical shape and the effect of cusp-type magnetic field was more noticeable when magnets are placed close to base metal. The welding speed can be increased without promoting weld imperfections and can result into much better bead appearance. Slight increase in value of D/W and improvement in penetration depth are well seen. Johanna Rosén, André Anders, *et al.* [20] constructed a study which shows under the Effect of magnetic field, when welding time is increased there is increase in nugget diameter by nearly 10% and the welding joint is more uniformly formed. Refine grains, uniformity of microstructure, reduction in segregations can be observed and better mechanical performance in tensile shear test and mechanical properties mainly plasticity are improved. Erik D. Taylor [36] showed that the shape of the weld bead can be improved by using magnetic arc oscillation and GTAW is used in welding of stainless steel and nickel alloys and conditions where good quality of the weld and the performance of the joint are considered to be important parameters.

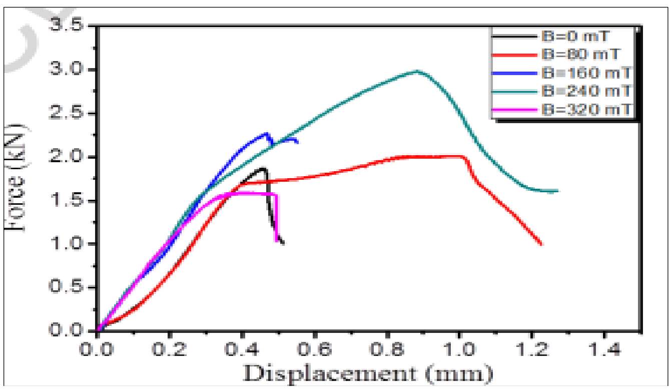

Fig 3: Shear strength curves for different intensities of external magnetic field.

Chang Yun long, LIU Mingxu, *et al.* [7] revealed in their examination that use of Longitudinal Magnetic Field on the CO_2 Arc Shape that is used for the joining of the pipes and the tubes with welding pressure upto 300 bar, exhibits good structural properties. And to determine the ductility, of the MIAB welded tubes Root bent test is conducted on them. S. Arungalai Vendan, S. Manoharan, *et al.* [12] conducted an examination of Magnetically Impelled Arc Butt Welding of alloy steel tubes in boilers and claimed that the hybrid solid state welding which is suitable for joining of butt in hollow cylindrical sections likes pipes and tubes mainly made of steel alloy with dimensions of 48mm diameter and 6 mm thickness . The range of welding current is 400-500A and the range of voltage is 90-120V. For this purpose, ESAB power source is used. This hybrid method is known as Magnetically Impelled Arc Butt Welding (MIAB).

Y.H. Kang *et al.* [27] studied that in Narrow Groove Gas Metal Arc Welding, the use of Electromagnetic Arc Oscillation slightly increases weld penetration with increased arc oscillation frequency along with the increase in the magnetic flux density. Root opening width was used for determining the arc shape and the oscillation width. Also magnetic field density used was upto 50 gauss with a root opening of about 10mm. Shan Ping and Li Yang *et al.* [21] examined the reconstruction of current density distribution in weld area during resistance spot welding of Aluminum alloy based on magnetic field and found that during the resistance spot welding process the current density is higher at the rim of the nugget than at the center of the nugget.

Marcel Bachmann and Avilov *et al.* [28] abstracted Numerical assessment and experimental verification of the influence of the Hartmann effect in laser beam welding process by steady magnetic fields. The magnetic field density ranging from 0.5T and 1T which changes the weld pool dimensions without any change in the flow characteristics in the weld pool. For larger weld bead dimensions the Hartmann effect works more efficiently. F.F. Curiel and R.Garcia *et al.* [30] studied the effect of magnetic field applied during gas metal arc welding on the resistance to localized corrosion of the heat affected zone in AISI304 stainless steel and researched that lower Degree of Sensitisation was induced with the application of the magnetic field. Resistance to pitting and intergranular corrosion was increased with the application of axial magnetic field during Gas metal Arc welding of stainless steel. Jones and TW Eagar *et al.* [32] projected the effect of magnetic forces acting on molten drops in gas metal arc welding found that a neck formation takes place when the drop detaches from the solid electrode and the divergence of the current increases in the drop neck. The shape of the drop's surface is determined by magnetic force on the drop. Magnetic force does not depend on the velocity of the fluid but depend on the shape of the current path.

P. Kanjilal and S.K. Majumdar *et al.* [33] studied the combined effect of flux and welding parameters on chemical composition and mechanical properties of submerged arc weld metal using fluxes CaO, MgO, CaF_2 andAl_2O_3. Polarity is found one of the most important welding parameters.

Yun Long Chang, Xiao Long Liu, *et al.* [1] investigated through Impacts of external longitudinal magnetic field on arc plasma and droplet during short-circuit GMAW and concluded that the in case of laser welding of hot cracking sensitive aluminum alloys, application of alternating magnetic fields shall provide sufficient silicon content that will suppress to hot cracking throughout the weld and magnetic field is used to influence the weld bead and for aluminum alloys. Under steady magnetic fields, the forces acting against the direction of original melt flow, will results in changing the direction of melt flow and also change in damping is observed. They also found that Magneto-hydro-dynamic theory is used to describe the interaction between an electrically conducting fluid and electromagnetic field. If there is in-homogeneity of magnetic field distribution, it results in maximum effects of volume which is induced in the rear upper part of the melt pool.

Sheng Zhu and Qiwei Wang *et al.* [6] research on droplet transfer of MIG welding with alternating longitudinal magnetic field and it was found that when there was no longitudinal magnetic field the mode of the droplet transfer was typical globular transfer and with the application of the longitudinal magnetic field the mode of droplet transfer changed from globular transfer to rotating spray transfer.

V. V. Chigarev, V. I. Shchetinina, *et al.* [2] studied Magnetic field in electric arc welding and reflected that 2 fluxes used were made of SiO_2 and TiO_2 in which TiO_2 flux had no effect on the arc voltage and SiO_2 flux increased the arc voltage. With the further use of SiO_2 flux the arc shape changed and there was no change in the arc shape using TiO_2 flux. There was sudden increase in the weld penetration by use of both fluxes. M.Gatzen, Z. Tang [3] used CFD-based model for melt flow in laser beam welding of aluminum with coaxial magnetic field and showed that the light intensity should be limited to dynamic range of the detector and sensitivity of detector remains same for all measurements was the major requirement. The transition point and transformation from the diffuse to diffuse column occurs when arc light intensity above a certain current is used. There was difficulty in numerical analyze of the image by using film camera therefore this difficulty was overcome by use of digital imaging system camera which provided immediate access to light intensity, which can determine changes in arc mode either during or after the experiment is done. By applying axial magnetic field, the transition point is shifted to higher current. The transition point and transformation from the diffuse to diffuse column occurs when arc light intensity above a certain current is used. Her-Yueh Huang [4] and LI Qing-ming *et al*. [5] examined the effects of activating flux on the welded joint characteristics in gas metal arc welding. By the use of Electromagnetic arc oscillation a narrow weld groove was developed due to increase in penetration depth which is an important technique for increasing productivity for manufacturing of thick walled components. Also polarity was found to be one of the most important parameters among the welding parameters, which are used to determine the yield strength and the hardness of a weld. The mixtures of flux variables are used for determining the impact toughness. R.Sivasankari and V.Balusamy *et al*. [11] investigated the characterization of magnetically impelled arc butt welded T11 tubes for higher pressure applications and researched that for the high pressure applications the joint exhibited good structural property. Under the quenching and the tempering conditions low alloy steels exhibit good toughness properties.

Garcia-Renteria *et al*. [31] revealed in their experiment that the presence of electromagnetic field lines during gas metal arc (GMA) welding of duplex stainless steel (DSS) at weld metal and high temperature heat affected zone induced positive modifications in the micro structural transformations of the metal which results in the formation of a passive surface film more resistant to localized corrosion. Also this passive film offers great resistance to localized attack in 3.5% NaCl solution when compared to joints welded without the application of external magnetic field. Sheng Zhu, Qiwei Wang, *et al*. [6] researched on Droplet Transfer of MIG Welding with Alternating Longitudinal Magnetic Field and reported that weld arc shape can be controlled by external longitudinal magnetic field. With increase in current, the shape of weld arc from top was constricted and from bottom it was expanded (like a bell). With increase in excited frequency, the arc shapes expands first and then the arc contour becomes smaller in certain range and the optimum combination of magnetic parameters was 2A and 60Hz.

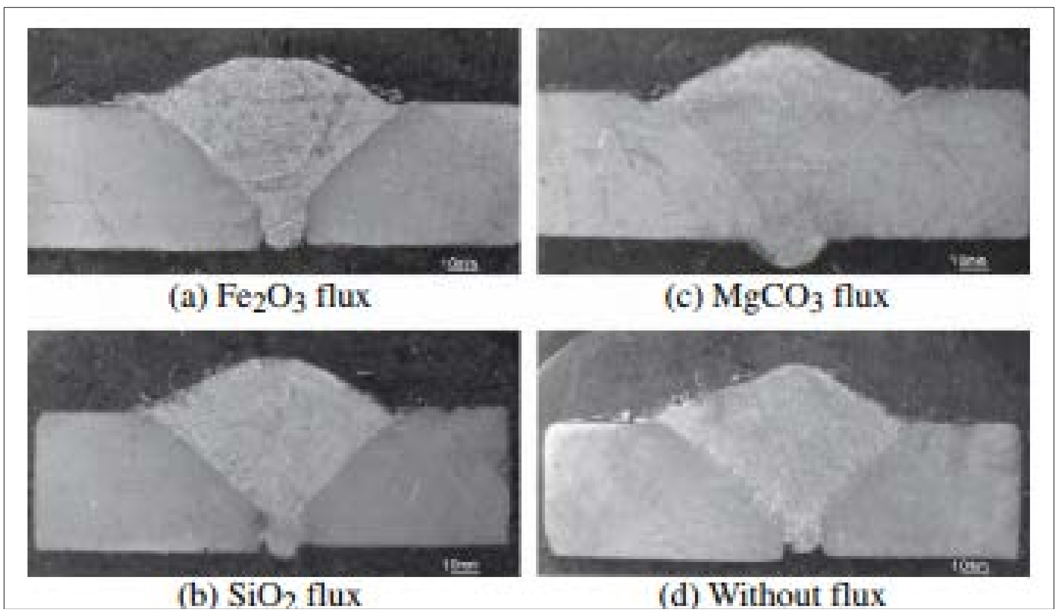

Fig 4: Effect of activating fluxes on the morphology of carbon steel welds.

F.Molleda and J.Mora *et al*. [9] studied the importance of spatter formed in shielded metal arc welding and found the formation of thin recrystallised region in the heat affected zone. Y.S. Tarng and W.H. Yang [26] studied optimization of weld bead geometry in gas tungsten arc welding by the Taguchi method and found that the various welding process parameters were improved by the taguchi method. Her-Yueh Huang [4] made use of Taguchi method to determine the effect of each welding parameter on weld bead geometry and found that, only three parameters played a significant role in optimal bead geometry i.e. arc voltage, welding speed and welding current with corresponding values of 23.3V, 454mm/min, 220A with a joint gap of 2mm. Further the use of fluxes Fe_2O_3, SiO_2 and $MgCO_3$ improved weld penetration and also tensile strength and hardness of welded joint. Correspondingly Ajit Senapati [25] revealed that longitudinal magnetic field applied to welding direction affects bead width of joint and greatly reduces it, also the formation of undercuts and spatter in also eliminated, further the tensile strength of joint, hardness and toughness is also increased due to improvement in grain structure of base metal. But when solenoid is introduced in transverse direction then mechanical properties such as hardness, toughness and tensile strength are reduced.

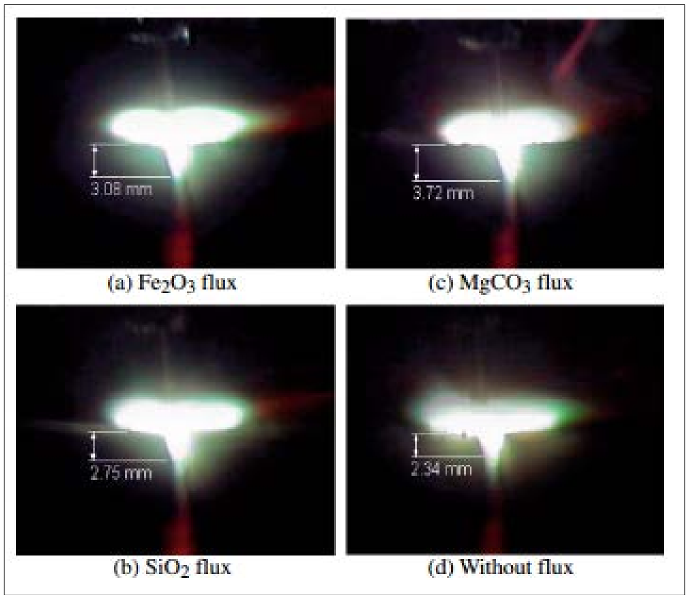

Fig 5: Arc images of GMAW of carbon steel without and with flux compositions.

Results & discussion

The external magnetic field which when applied during the process of arc welding results in various positive outcomes such as refinement of grain structure of base metal and increase in weld nugget diameter as well, the welding speed can be increased without promoting weld imperfections along with decrease in spatter and undercuts, increase in penetration depth which results in increase in tensile strength and impact toughness of the welded joint. Further, by the use of external magnetic field the direction of arc plasma can be easily varied, but application of external magnetic field above critical value will cause burning of weld bead which will result in surface roughness decreasing the joint efficiency, hence intensity of magnetic field should be kept within the certain permissible limits.

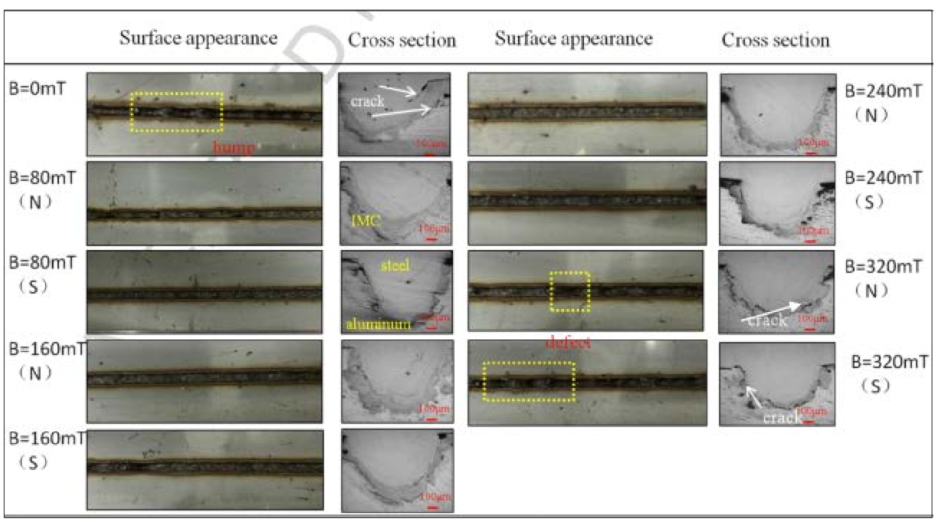

Fig 6: Surface appearance and cross sections of joints in different magnetic fields

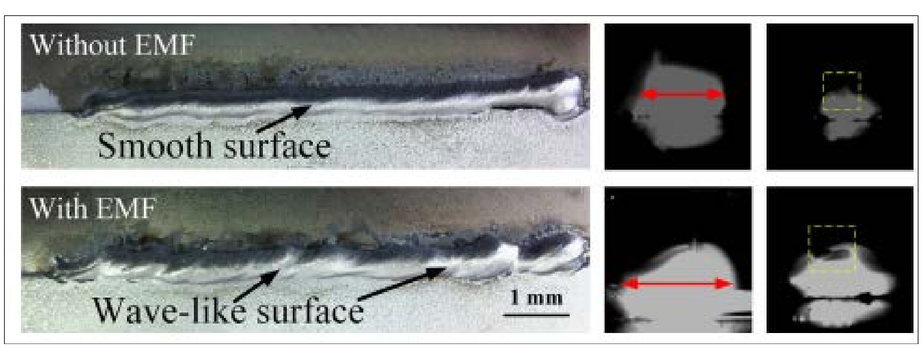

Fig 7: Weld appearance and morphologies of weld arc and molten drop.

Conclusion

A large number of articles were reviewed on various input and output parameters and following conclusion can be drawn from this review:

Not much work has been reported on changes in weld quality and weld geometry when arc welding is performed in presence of external magnetic field. It is clear now that with the use of external magnetic field various properties of welded joint such as increase in weld nugget diameter, weld penetration, tensile strength, reduction in weld spatter and grain refinement of structure takes place. All these factors contribute in increase of life of arc welded joint and so as the article. The main parameters which contributes in change of properties of welded joint are direction of applied external magnetic (longitudinal or transverse), speed of welding, intensity of applied magnetic field.

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