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Evaluation of Arc Welding Process Practical Capability According to Joint Design Requirements

Kawakib A. K. Al- Mendwi*, Qasim M. Doos

Mechanical Engineering Department, Baghdad University, Baghdad, Iraq.

*Corresponding Author E-mail: Kawakib.Mendwi@coeng.uobaghdad.edu.iq

ABSTRACT: The difference between arc welding processes characteristics leads to variation between process capabilities. Similarly, welded joints vary based on design and other technical requirements. These variations deem certain processes more suitable to weld a specific joint while others might be unsuitable for the specific task. In this work a software to facilitate the identification and selection for five arc welding process base on their design and technical differences was developed. These arc welding methods are: shielded metal arc welding (SMAW), gas metal arc welding (GMAW), submerged arc welding (SAW), flux cord arc welding (FCAW) and gas tungsten arc welding (GTAW). The software model that developed in this paper consists of two main modules. The first module examined the weldability of the nine most common metals and alloys based on the relationship between the alloy nature and its thickness regarded to the five arc welding processes. The second module deals with compatibility between these welding processes and the joint configurations like joint type, edge and thickness. The new software was successfully verified on twelve case studies. Using software to screen the most capable processes is a precursor for automating the process of selecting the optimal welding process for the specific joint.

KEYWORDS: Computer aided Arc welding process capability, Material type, Material thickness, Joint type, Joint configuration.

INTRODUCTION

The welding or fusion joining processes is a permanent bonding process between two or more parts with or without filler metal, through the melting and fusing together of adjacent portions of the originally separate pieces. Generally, high temperatures beyond the melting point are produce by electric arc plasma, but in a few other welding methods the bond can be achieved by using alternative means. There are many methods for classifying arc welding processes such as by energy source, electrode type, shielding method, [1, 2], etc. The choice of a specific arc welding process depends on many factors including cost of production; working sequence; structural (mass) size; joint design; desired performance; end use of the joint; experience and abilities of manpower; parent metal and its metallurgical characteristics; types of joint, location, welding position; required accuracy of assembly; joint accessibility; welding equipment available; and welder skill. Usually, many welding processes can be used for a specific welding job. The two most critical factors that influence the process choice are the technical requirements and cost [3]. AWS defined the weldability as: "Weldability is the capacity of a material to be welded under the imposed fabrication conditions into a specific suitably designed structure and to perform satisfactorily in the intended service."

This definition implies that the same metals considered exhibiting a good or poor weldability under different conditions [4]. Weldability can be subdivided in to fabrication weldability and service weldability. Fabrication weldability is concerned with the easiness of welding the specific material, while service weldability is concerned with the successful welding of a specific joint configuration (geometry and material) utilizing a specific process [5]. Fusion arc welding, and electric resistance welding processes are between the most popular welding processes, as these are capable to produce a welded joint that can have a strength and toughness equal to, or greater than the welded materials. Service weldability is directly related to joint complexity, the more complicated the joint, the more difficult the welding to be [6]. The combination of (material – method of welding) has its own weldability characteristics and common welding defects. Thus, a satisfactory welded joint requires a good understanding of the factors that governs or influence the relation between the material weldability and the welding process. The materials factors that affected its weldability are: compositional heterogeneity, chemical composition, dimensions and cross-sections, metallurgical and physical condition prior to welding, physical properties, and mechanical constraints. While the factors that affected process capability are: rate of energy input, energy source, degree of automation, and welding environment. The most popular welding processes are: SMAW, GMAW, GTAW, FCAW, Oxyacetylene Arc Welding (OAW), and Torch or oxyfuel Brazing (TB) [7].

Each welding process has its own characteristics that lead to different economic performance and different environmental impacts especially in heavy industry because of using huge amount of material and electricity [8]. The complexity in choosing a welding process consists from the large number of selection parameters that are often inter-dependent and contradictory in effect [9], while the performance of an engineering component is limited by the properties of its material and by the shapes to which this material can be formed [10]. The quality of the weld joints depends on the bead geometry and shape factors [11]. Some engineering materials have their own properties, but when joining these materials, they perceive some changing in these properties [12]. With the advent of technology the industry is continually moving from relying on the experts to computerized expert systems. To select the optimum welding process or a specific joint, a process capability check is completed as a precursor to the optimization process. This will ensure that the selected optimal process is capable of performing the weld of the specific joint [13, 14].

THE METHOD FOUNDATION

In this work a computer aided welding capability method is suggested and software was developed base on the suggested method. This section describes the architecture of the developed software and the underlying method. The method is based on evaluating the work piece weldability using each evaluating arc welding process as well as, the assessment of the compatibility of each process with the welded joint configuration. The weldability and compatibility assessment is curried out based on empirically established parameters in the industry. The parameters used in this work is collected from multiple sources including summarized parameters that are available in published scientific literature [15 – 22], parameters published by major welding suppliers [23 – 37] and direct input from industry experts [38].

Figure 1 shows the software architecture which is constitute from a weldability module, compatibility module and final comparator. The weldability module function is to assess the capability of each arc welding process to produce a sound welding joint in a substrate made of a specific material and thickness. The compatibility module evaluates the fitness of each arc welding process to weld a joint of a specific type, thickness and edge preparation. Finally the comparator will screen the processes that successfully pass both evaluations. The program was constructed to express the proposed system which employed C++ program language. Table 1. represent the technical comparison between arc welding processes which shows the variations and differences between each process which extracted from a collection of web pages related to major welding suppliers [13 – 27].

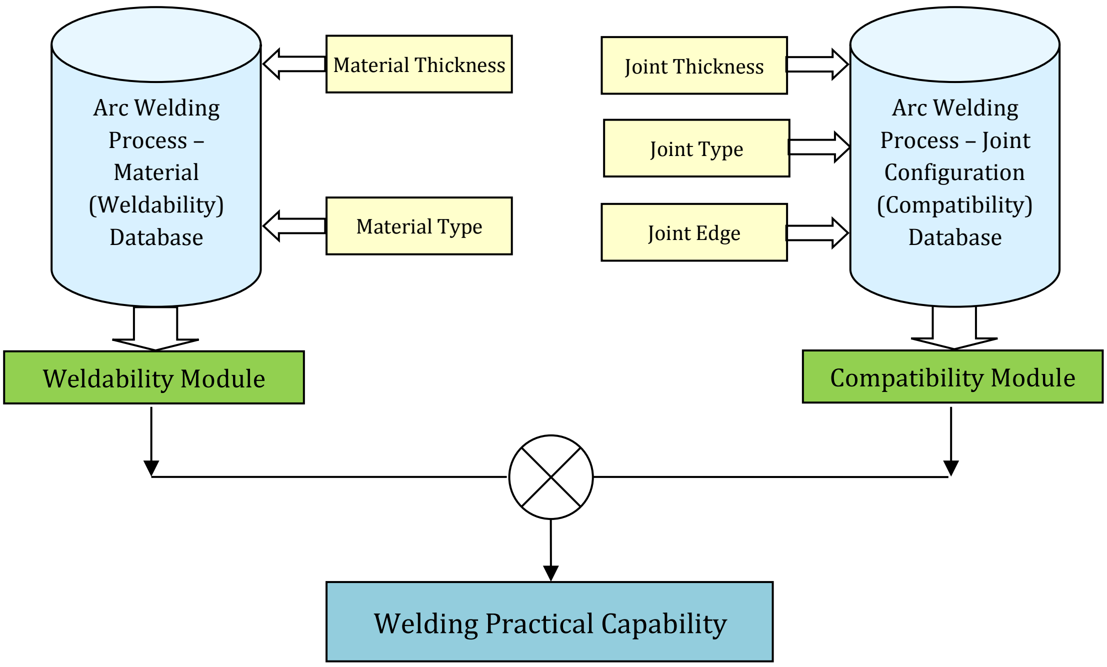


Figure 1. The architecture of the program.

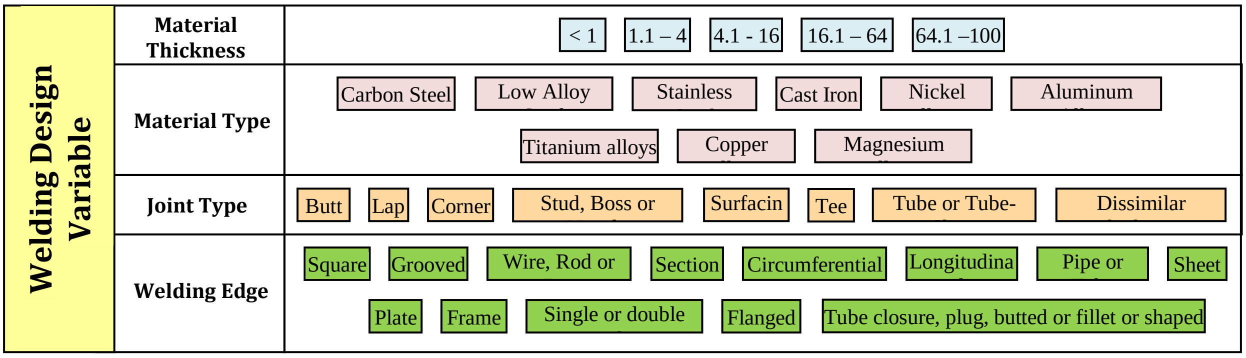


Figure 2: The welding design variable

Table 1: Technical Comparison between Arc Welding Processes [13 – 27]

	SMAW	SAW	FCAW	GMAW	GTAW
Electrode type	Consumable	Consumable	Consumable	Consumable bare	Non Consumable
Filler type	Stick	Granulated	Hollow wire	Sold wire	Stick
Filler metal	Same us electrode	Added with flux	Same us electrode	Same us electrode	Externally added
Feed type	Intermittent	Continues	Continues	Continues	Intermittent optional
Electrode diameter (mm)	(1.5 – 10)	(0.8 – 4)	(1.6 – 6)	(0.6 to 6.4)	(1 to 8)
Shielding method	External flux	Gravitated flux	Internal flux	Argon and/or helium	Argon and/or helium
Flux type	Sold	Granulated	Sold	Gas	Gas
Current type	AC / DC	AC / DC	AC / DC	AC / DC	AC / DC
Current rang (amp)	(75– 400)	(150 – 3500)	(80 – 800)	(75 – 400)	(60-375)
Speed (ipm)	(3 – 6)	(4 – 150)	(3 – 25)	(6 – 10)	(4 – 6)
Deposition amount / hour	(1.5 – 12.6) lbs/hr	(7 – 48) lbs/hr	(3.2 – 30) lbs/hr	(1.9 – 17.1) lbs/hr	(0.5 – 5)lbs/hr
Degree of automation	Manual	Semi-Auto	Semi-Auto	Semi-Auto	Manual

SOFTWARE ARCHITECTURE

The software main form showing the menu bar of the developed Arc Welding Process Capability System (AWPCS) is shown in Figure 3. The drop down menu of the AWPCS system consist of three subsystems, the first one named “Weldability of Materials”, the second subsystem named “Welding Compatibility”, and third subsystem named “Welding Capability.

Weldability of Materials

The first subsystem deals with the compatibility between material – welding processes, and the materials that examined in the program are: a. Carbon steel, b. Low alloy steel, c. Stainless steel, d. Cast iron, e. Nickel and alloys, h. Aluminum and alloys, i. Titanium and alloys, j. Copper and alloys, k. Magnesium and alloys, l. Refractory alloys. Figure 4 shows the weldability of material form.

Welding Compatibility

The second subsystem deals with the compatibility between joint design – welding processes, and the joints that examined in the program are: a. Butt, b. Lap, c. Corner, d. Tee, e. Stud, Boss and Nozzle, f. Tube / Tube-sheet, g. Dissimilar Thickness, h. Surfacing. Figure 5 shows the welding compatibility form.

Butt Joint

If the user selects the option button “Butt” a new form with all types of edge type compatible with it as shown in Figure 6, and the edge type are: a1. Square edge, single or double-sided., plate, Sheet, and longitudinal in tube, a2. Grooved. single or double-sided, Plate, Sheet, and longitudinal in pipe or tube., a3. Wire, rod or bar., a4. Circumferential. Tube up to 100 mm outside diameter, a5. Circumferential. Pipe > 100 mm outside diameter, a6. Section.

Lap Joint

When the user selects the option button “Lap” a new form with all types of edge type compatible with it as shown in Figure 7, and the edge type are: b1. Sheet and plate. b2. Wire or rod to sheet or plate.

Corner Joint

When the user selects the option button “Corner” a new form with all types of edge type compatible with it as shown in Figure 8, and the edge type are: c1. Sheet or plate. c2. Flanged. c3. Frame in bar, miter or square. c4. Frame in tube or hollow section. c5. Frame in section, miter or square.

Tee Joint

When the user selects the option button “Tee” a new form with all types of edge type compatible with it as shown in Figure 9, and the edge type are: d1. Sheet or plate, fillet. d2 Sheet or plate, full penetration. d3. Sheet, flanged. d4. Structural. d5. Pipe, structural. d6. Pipe, for flow.

Stud, Boss and Nozzle Joint

When the user selects the option button “Stud, Boss and Nozzle” a new form with all types of edge type compatible with it as shown in Figure 10, and the edge type are: e1. , set on, e2. set in. e3. set through. e4. , flanged, set on. e5. flanged, set in. e6. flanged, set through.

Tube / Tube-Sheet Joint

When the user selects the option button “Tube / Tube-Sheet” a new form with all types of edge type compatible with it as shown in Figure 11, and the edge type are: f1. Tube / Tube-sheet or flange (front face). f2. Tube / Tube-sheet or flange (front face trepanned). f3. Tube / Tube-sheet or flange (back face). f4. Tube / Tube-sheet or flange (formed or machined). f5. Tube closure, disc and corner weld. f6. Tube closure, disc and flange. f7. Tube closure, cap (exterior). f8. Tube closure, cap, (interior, inwards). f9. Tube closure, cap, (interior, outwards). f10. Tube closure, plug and fillet. f11. Tube closure, plug, shouldered. f12. Tube closure, plug, (shaped). f13. Tube closure, plug, (butted). f14. Tube closure, plug, (butted, recessed).

Dissimilar Thickness Joint

When the user selects the option button “Dissimilar Thickness” a new form with all types of edge type compatible with it as shown in Figure 12, and the edge type are: g1. Butt, tapered. g2. Butt, rebated. g3. Fillet or lap. g4. Tee.

Surfacing Joint

When the user selects the option button “Surfacing” a new form with the compatible type with it as shown in Figure 13, and the edge type are: h1. Thickness refers to clad layer.

Welding Capability

The third subsystem distinguished and displayed the result of the two previous subsystems as shown in the Figure 14.

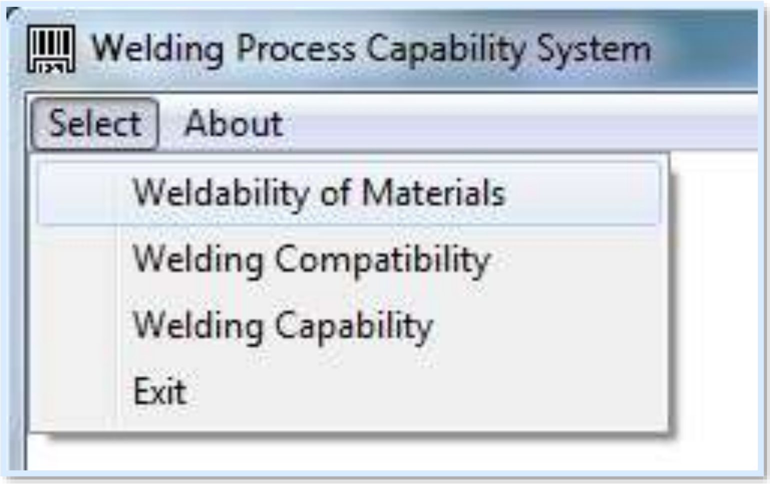


Figure 3. The software main form

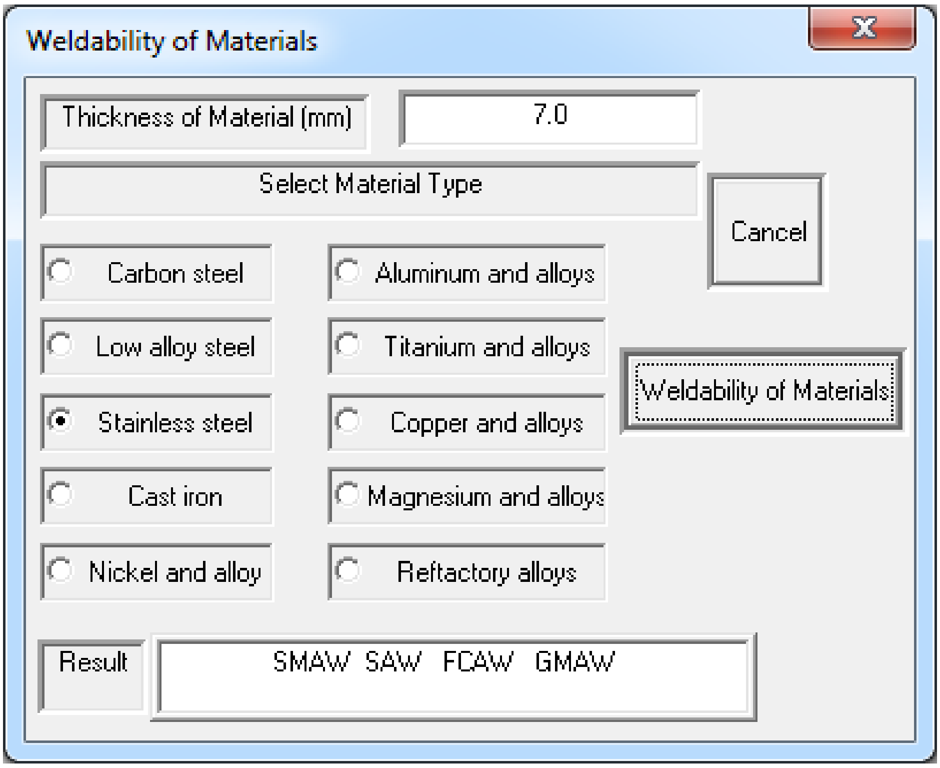


Figure 4. Weldability of material form

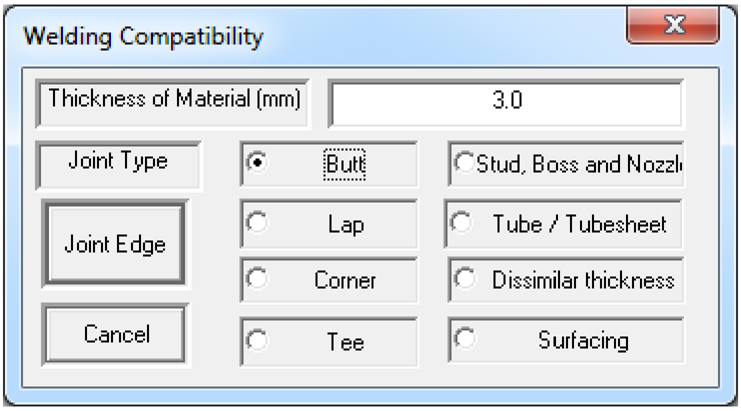


Figure 5. Welding compatibility form

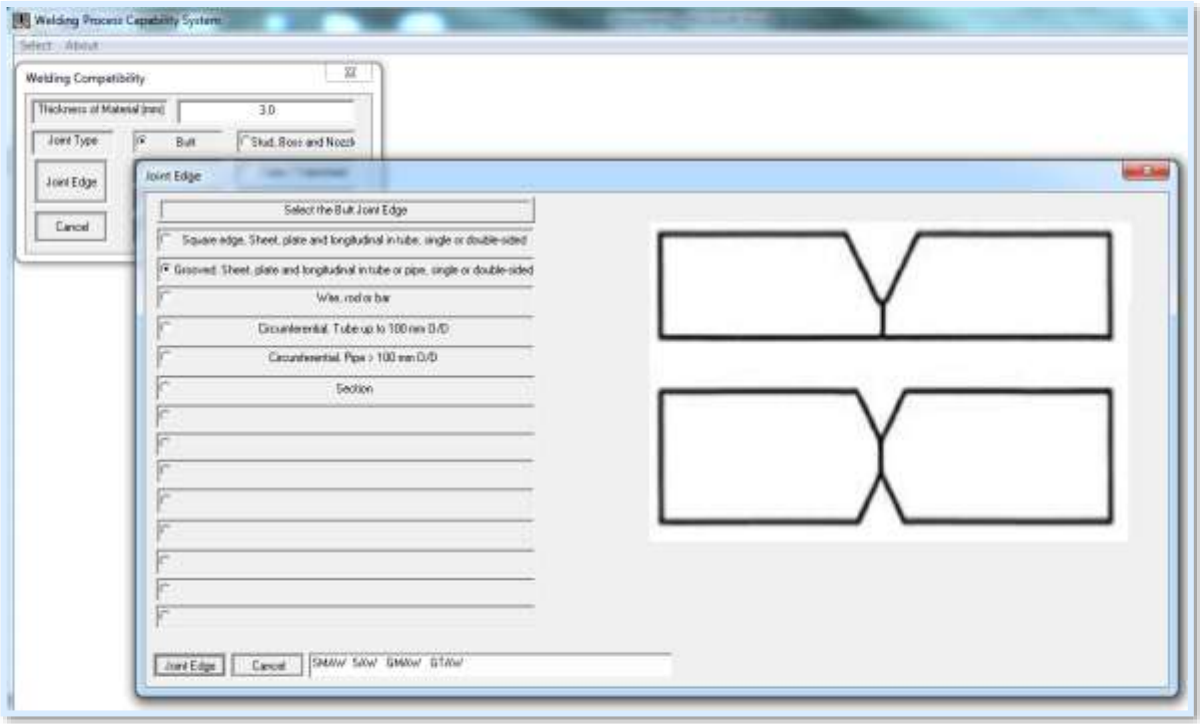


Figure 6. Welding compatibility form showing the joint edges types that corresponding to (Butt) joint

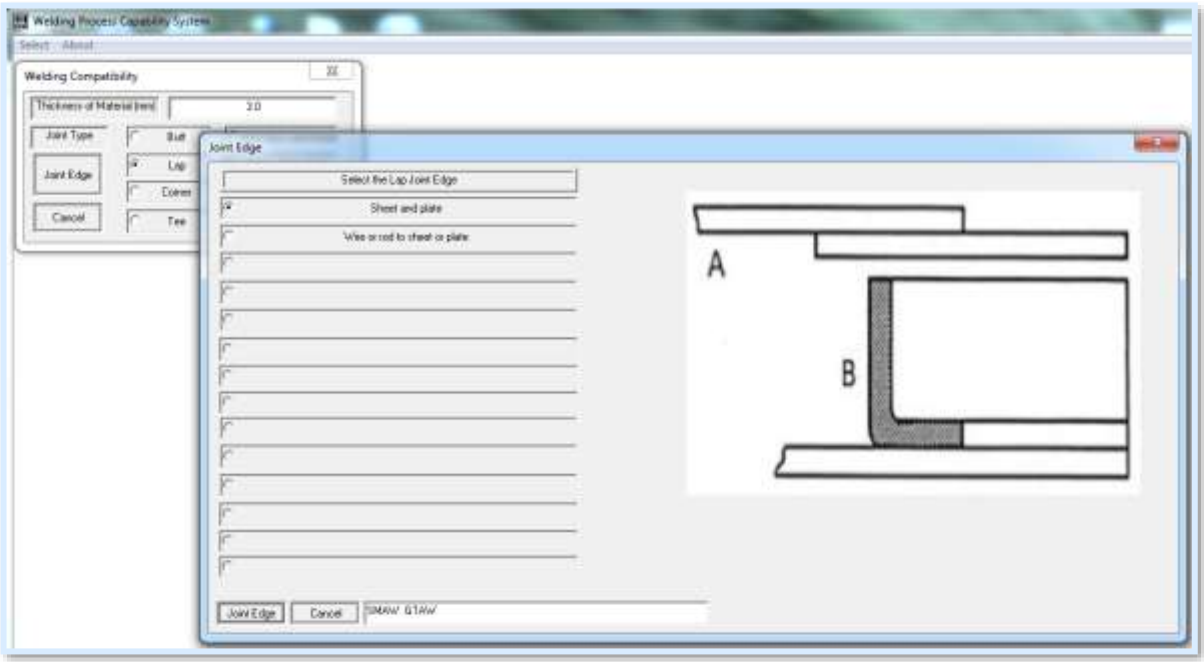


Figure 7. Welding compatibility form showing the joint edges types that corresponding to (Lap) joint

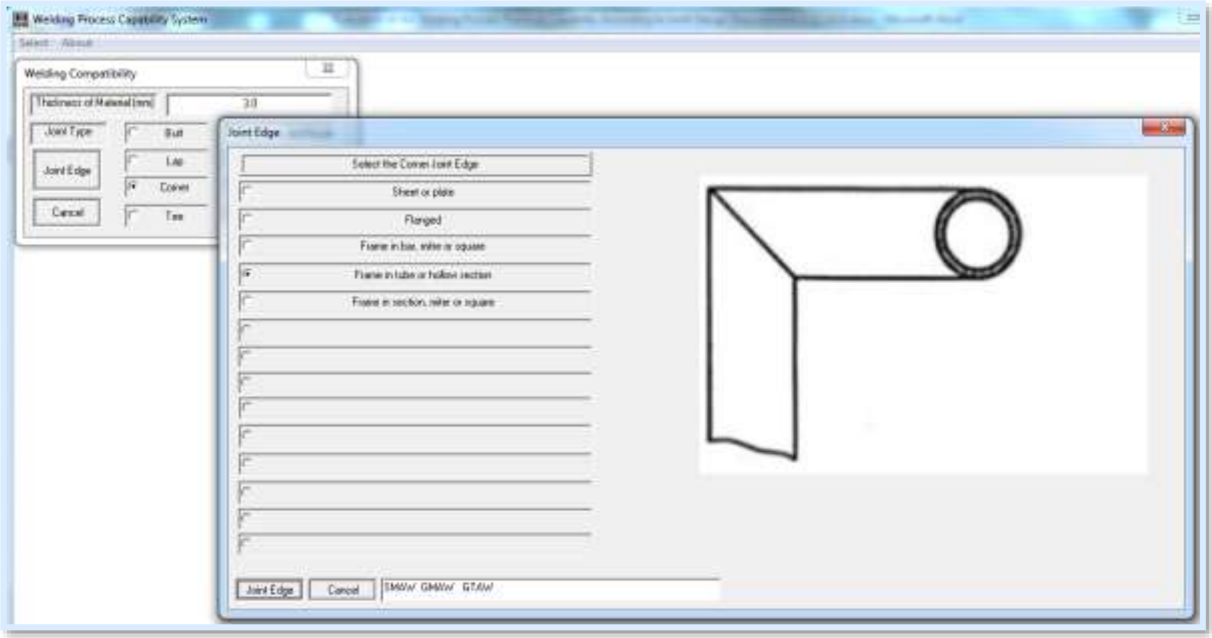


Figure 8. Welding compatibility form showing the joint edges types that corresponding to (Corner) joint

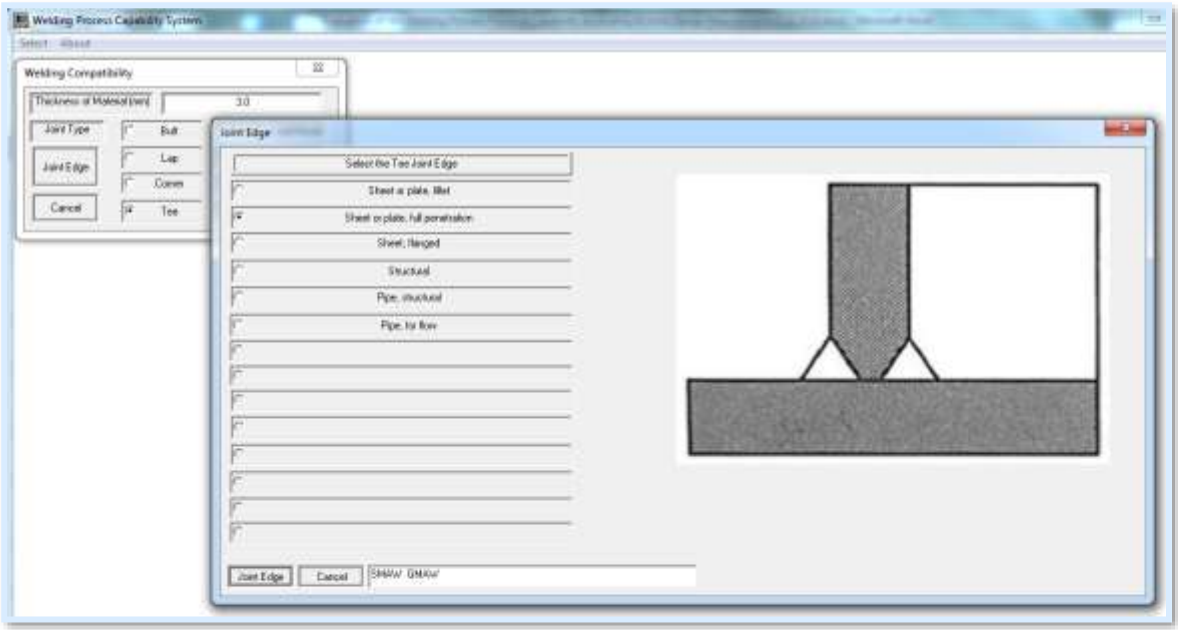


Figure 9. Welding compatibility form showing the joint edges types that corresponding to (Tee) joint

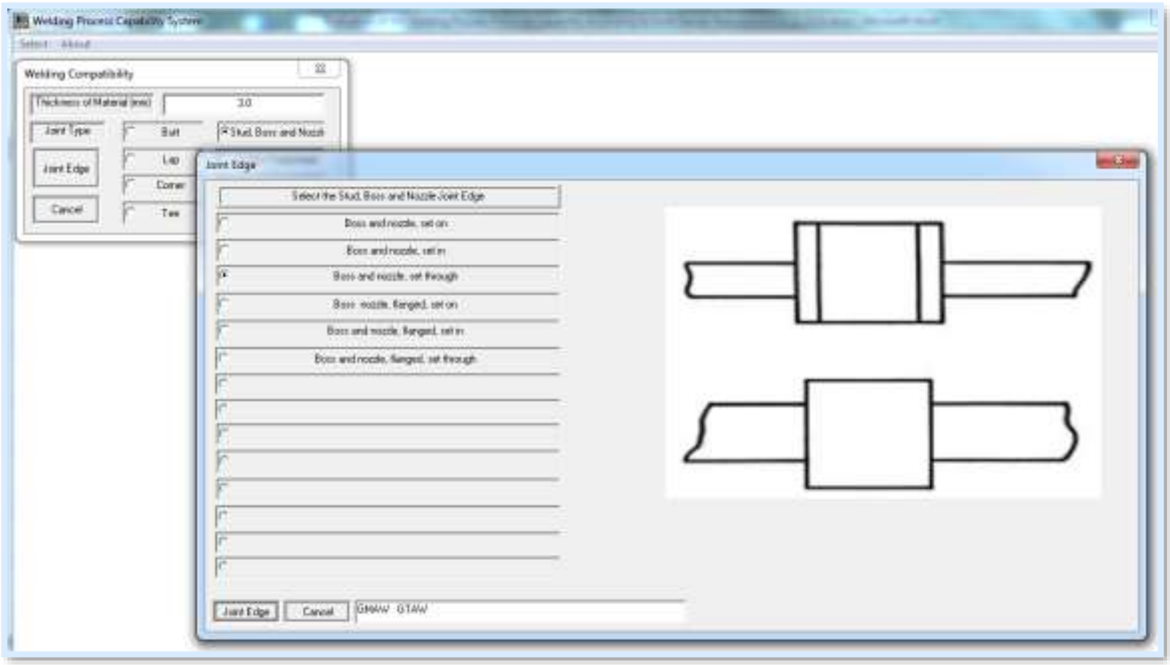


Figure 10. Welding compatibility form showing the joint edges types that corresponding to (Stud, Boss And Nozzle) joint

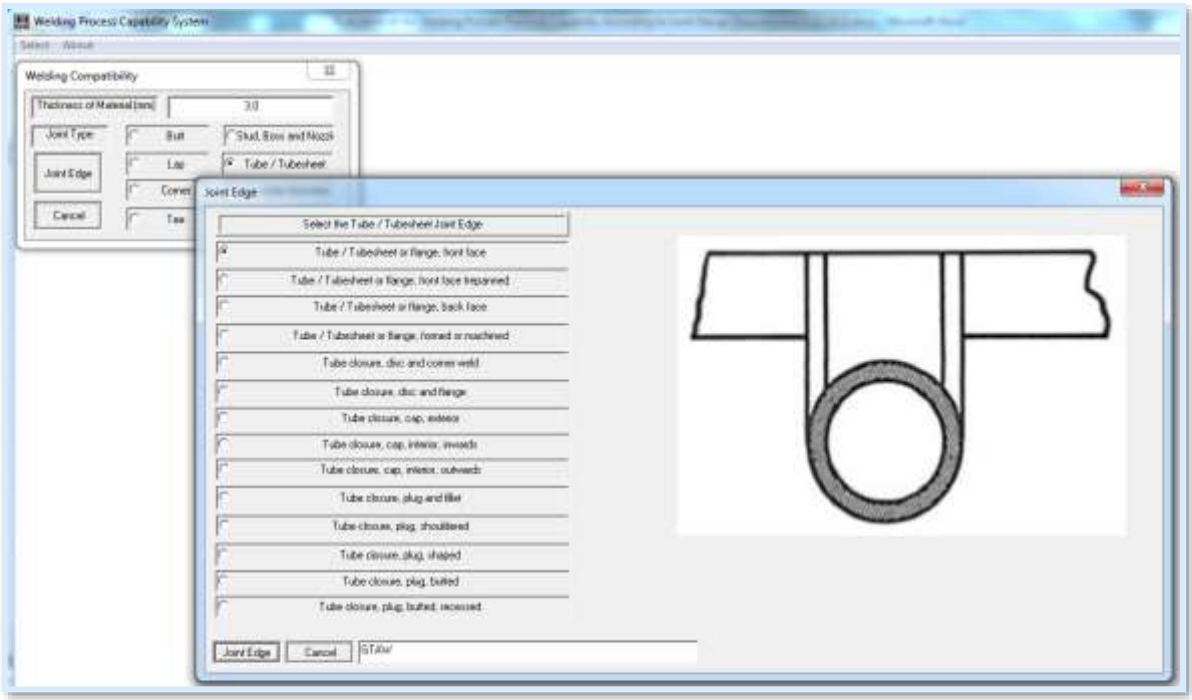


Figure 11. Welding compatibility form showing the joint edges types that corresponding to (Tube / Tube-Sheet) joint

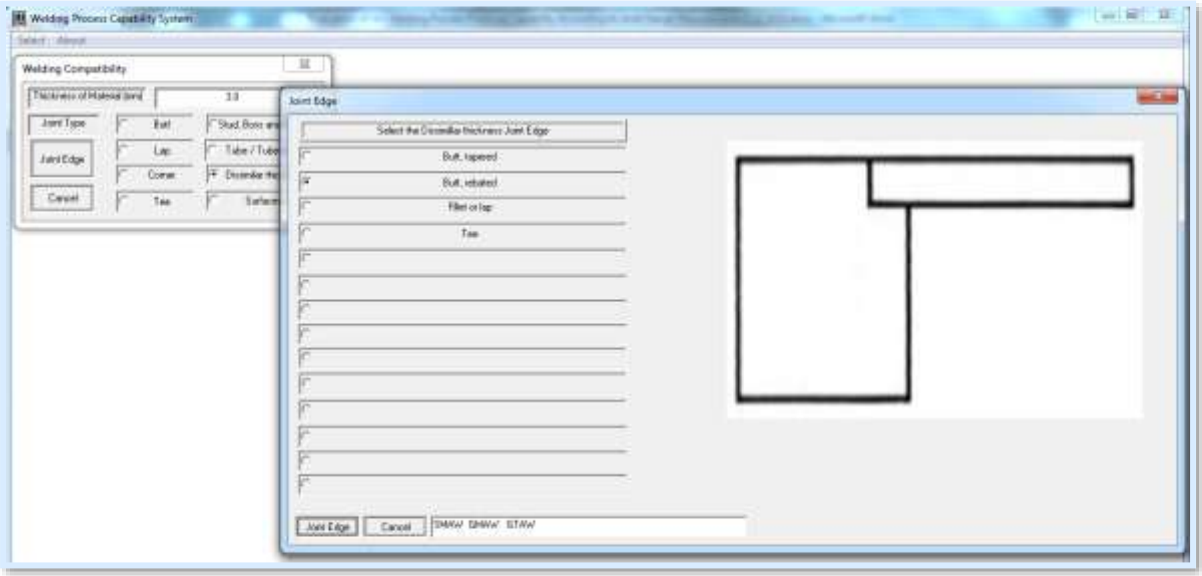


Figure 12. Welding compatibility form showing the joint edges types that corresponding to (Dissimilar Thickness) joint

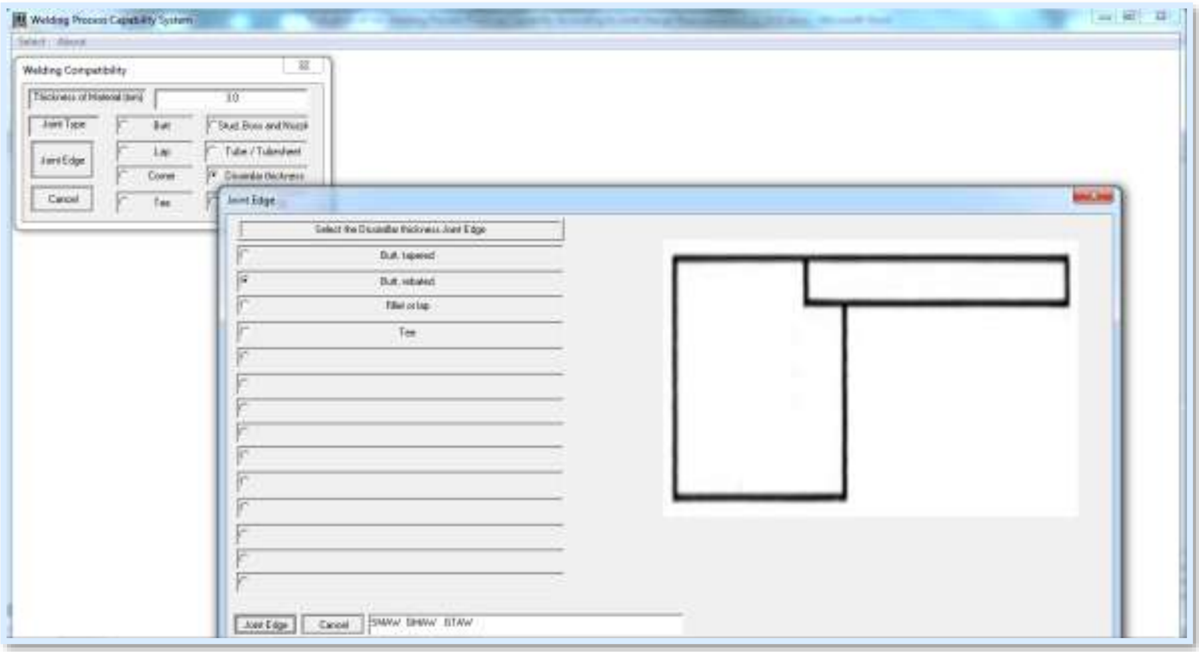


Figure 13. Welding compatibility form showing the joint edges types that corresponding to (Surfacing) joint

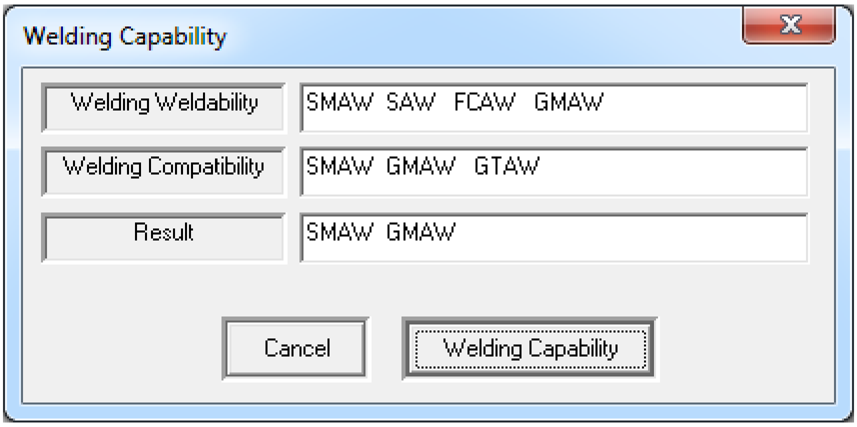
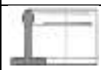
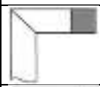
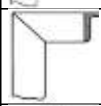
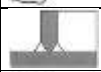
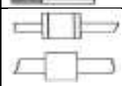


Figure 14. Final result of the two subsystems

APPLICATION AND RESULTS

To test the new software case studies were implemented on twelve types of welding joints that are parts of the following products: [Ladder, Staircase, Measurement bar, Frame, Gable Trusses shapeliness, Tank (Shell – Bottom), Bridge, Tank drain nozzle, Heat exchanger Tubes sheet, Tube sheet dissamalir thickness, Surface facing (3) mm and Surface facing (5) mm]. The welded joint in the ladder staircase are for pieces of tube welding to longitudinal tubes all made of carbon steel (3) mm thick. The case results for applying the case study in the software are as bellow: By applying "Weldability of Material" the results was "SMAW SAW GMAW GTAW", by applying the "Welding Compatibility" the results was "FCAW GMAW GTAW" and by applying the "Welding Capability" the results was "GMAW GTAW". Table 2. shows the details for each of the twelve case studies, while Table 3. shows all the software results for each of the case studies

Table 2. Case Studies Descriptions and Application

No.	Name	Description	Material	Thickness (mm)	Joint Type	Joint Edge	Joint Shape
1	Ladder	Equipment access ladder	Carbon Steel	3	Butt	Circumferential. Tube up to 100 mm O/D.	
2	Staircase	Building access staircase	Carbon Steel	3	Lap	Wire or rod to sheet or plate.	
3	Measurement bar	Liquid depth metering bar with (3 – 4) in cross section welded along the tank	Carbon Steel	3	Butt	Section	
4	Frame	Room window Frame	Aluminum	6	Corner	Frame in bar, miter or square	
5	Gable Trusses shapeliness	Gable roof support truss (5 – 12) peace	Carbon Steel	6	Corner	Frame in section, miter or square	
6	Tank (Shell – Bottom)	Storage tank (Welding the shell to the bottom plate)	Carbon Steel	12	Tee	Sheet or plate, full penetration	
7	Bridge	Bridge structure from 30 peace and up	Carbon Steel	45	Tee	Structural	
8	Tank drain nozzle	Coupling welded to the tank shell for the drain nozzle	Carbon Steel	10	Stud, Boss and Nozzle	Boss and nozzle, set through	

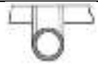
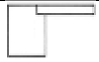
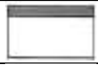
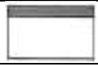
9	Heat exchanger Tubes sheet	Heat exchanger tubes to tube-sheets welding	Stainless steel	3	Tube / Tubesheet	Tube / Tubesheet or flange, front face	
10	Tube sheet dissamalir thickness	Tube-sheet (20) mm thickness to shell (100) mm	Alloy Steel	20	Dissimilar thickness	Butt, rebated	
11	surface facing 3 mm	(3) mm facing cap over (6) mm joint	Stainless steel	3	Surfacing	Thickness refers to clad layer	
12	surface facing 5 mm	(5) mm facing cap over (11) mm joint	Stainless steel	5	Surfacing	Thickness refers to clad layer	

Table 3. The software results for the case studies

No.	**Name**	**Weldability**	**Compatibility**	**Capability**	**Not Capabile**
1	Ladder	SMAW SAW GMAW GTAW	SMAW GMAW GTAW	SMAW GMAW GTAW	SAW FCAW
2	Staircase	SMAW SAW GMAW GTAW	SMAW GMAW GTAW	SMAW GTAW	SAW FCAW GMAW
3	Measurement bar	SMAW SAW GMAW GTAW	SMAW GMAW GTAW	SMAW GMAW GTAW	SAW FCAW
4	Frame	SMAW GMAW GTAW	GTAW	GTAW	SMAW SAW FCAW GMAW
5	Gable Trusses shapeliness	SMAW SAW FCAW GMAW GTAW	SMAW GMAW	SMAW GMAW	SAW FCAW GTAW
6	Tank (Shell – Bottom)	SMAW SAW FCAW GMAW	SMAW SAW FCAW GMAW	SMAW SAW FCAW GMAW	GTAW
7	Bridge	SMAW SAW FCAW GMAW	SMAW FCAW GMAW	SMAW FCAW GMAW	SAW GTAW
8	Tank drain nozzle	SMAW SAW FCAW GMAW	SMAW GMAW	SMAW GMAW	SAW FCAW GTAW
9	Heat exchanger Tubes sheet	SMAW SAW GMAW GTAW	GTAW	GTAW	SMAW SAW FCAW GMAW
10	Tube sheet	SMAW SAW FCAW GMAW	SMAW SAW FCAW GMAW	SMAW SAW FCAW GMAW	GTAW
11	Weld join facing 3 mm	SMAW SAW GMAW GTAW	GTAW	GTAW	SMAW SAW FCAW GMAW
12	Weld join facing 5 mm	SMAW SAW FCAW GMAW GTAW	SMAW SAW FCAW GMAW GTAW	SMAW SAW FCAW GMAW GTAW	SMAW SAW FCAW GMAW GTAW

EVALUATION AND ANALYSIS

In order to evaluate and analyze the results from the program, the methods of welding processes were sorted according to their capability to weld the joints in the studied cases; also the incapable welding processes were sorted according to the type of incapability whether it was based on (Weldability), (Compatibility) or both.

Table 4. shows the capability of each method to weld the joint in each studied case, while Table 5. shows the reason for the incapability.

According to case studies results the following observations and analysis has been made:

SMAW: SMAW were capable in all the studied cases except case (11). In his case, the incapability were due to process compatibility with the low thickness cladding, as the elevated temperatures generated from the arc makes it difficult to control the welding process in low thickness cladding.

SAW: SAW was incapable, due to incompatibility in all the studied cases except (6, 10 and 12) where the welded components were plane surface with relatively higher thicknesses, since SAW is suitable for welding plane as well as cylindrical parts, with large diameter and thickness, that are rotatable allowing it to produce thicker welds in high quality with lower number of passes (down to one pass in many cases). The process met the capability due to weldability requirements in all the studied cases except (4) due to the low thickness and softness of the Aluminum, since SAW utilizes high current, high speed with high deposition rate.

FCAW: FCAW was only capable in the studied cases (6, 7, 10 and 12) as it comes next to SAW in voltage, speed and deposition rate, while, it was considered incapable in cases (1, 2, 3, 4, 9 and 11) in regards of weldability and compatibility due to the low thicknesses. In cases (5, 8) FCAW was suitable for the weldability requirements but failed the compatibility due to low thickness which lead to component melting because of the high temperatures generated in this process.

GMAW: GMAW met the weldability requirements for all of the studied cases, yet it was incompatible in cases (2, 4, 9 and 11) due to low metal thicknesses that is not suitable for the heat generated from GMAW process.

GTAW: GTAW is the least between the considered processes in regards to voltage, speed and deposition rate, which makes it not suitable for welding high thicknesses. This was the reason behind considering the process incapable and failing the weldability requirements in cases (6, 7, 8, and 10). Case (5) considered wieldable using GTAW yet it was considered incompatible due to high thickness.

Table 4. Case studies capability classifications

Welding Process	Capable	Not Capable
SMAW	[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12]	[11]
SAW	[6, 10, 12]	[1, 2, 3, 4, 5, 7, 8, 9, 11]
FCAW	[6, 7, 10, 12]	[1, 2, 3, 4, 5, 8, 9, 11]
GMAW	[1, 3, 5, 6, 7, 8, 10, 12]	[2, 4, 9, 11]
GTAW	[1, 2, 3, 4, 9, 11, 12]	[5, 6, 7, 8, 10]

Table 5: Not capable case studies classifications

Welding Process	Not Capable	Not Capable in Weldability	Not Capable in Compatibility
SMAW	[11]		[11]
SAW	[1, 2, 3, 4, 5, 7, 8, 9, 11]	[4]	[1, 2, 3, 4, 5, 7, 8, 9, 11]
FCAW	[1, 2, 3, 4, 5, 8, 9, 11]	[1, 2, 3, 4, 9, 11]	[1, 2, 3, 4, 5, 8, 9, 11]
GMAW	[2, 4, 9, 11]		[2, 4, 9, 11]
GTAW	[5, 6, 7, 8, 10]	[6, 7, 8, 10]	[5, 6, 7, 8, 10]

CONCLUSIONS

A system for screening the arc welding process that is capable of welding a specific joint is developed and programmed into software. The new software were carefully evaluated and discussed with industry experts. The results showed that the software and the underlying method produced accurate results. Even though, the software showed success in analyzing the studied joints, still, the full potential of the method lay in its adaptability to any potential work environment or special welding process. The adaptation of this method in any work environment can reduce the reliance on the welding experts and improve process selection reliability. This eventually will improve cost and productivity successful screening of the arc welding process that can perform a specific weld is the precise for selecting the optimum process for the specific joint.

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REFERENCES

[1] R. Creese, “Introduction to Manufacturing Processes and Materials”, New York: Marcel Dekker, 1999.

[2] J. Bralla, “Design for Manufacturability Handbook”, Second Edition, USA: McGraw-Hill Companies, 1999.

[3] M.I. Khan, “Welding Science and Technology”, New Delhi: New Age International (P) Limited Publishers, 2007.

[4] R. Messler, and W. Verlag., “Principles of Welding Processes, Physics, Chemistry, and Metallurgy”, Singapore: WILEY-VCH GmbH & Co. KGaA, 2004.

[5] M.F. Farag, “Materials and Process Selection for Engineering Design”, Second Edition, USA: CRC Press Taylor & Francis Group, LLC, 2008.

[6] J.A. Charles, F.A.A. Crane, and J.A.G. Furness, “Selection and Use of Engineering Materials”, Third edition, OXFORD: Butterworth-Heinemann, 2001.

[7] L. Jeffus, and L. Bower, “Welding Skills, Processes and Practices for Entry-Level Welders: Book 1”, Canada: Delmar, Cengage Learning, 2010.

[8] G. Sproesser, S. Schenker, A. Pittner, R. Borndörfer, M. Rethmeier, Y. Chang, and M. Finkbeiner, “Sustainable welding process selection based on weight space partitions”, *Elsevier, Science Direct, Procedia CIRP*, pp., 127 – 132, 2016.

[9] K. Al–Mendwi, “Computer Aided Selection of Materials by Use of Ashby’s Charts: A Balance State by Dimensionless Ranking”, *The 6th Engineering Conference, Volume III, Mechanical & Nuclear Engineering*, University of Baghdad, Iraq, Vol. 5, no. 7, pp., 391 – 399, 2009.

[10] K. Al-Mendwi, and Q. Doos, “Optimal Welding Process Selection to Fabricate Crude Oil Filter Tower Joints By Integration of Multi Criteria Decision Making Processes”, *Journal of Mechanical Engineering Research and Developments (JMERD)*, Vol. 42, no. 4, pp., 102-107, 2019.

[11] S. Alrabii, and T. Al, “Modeling and Optimization the Influence of CO2-MAG Welding Parameters on the Weld Joint Shape Factors”, *Journal of Engineering, Baghdad University*, Vol. 21, no. 10, pp., 70-89, 2015.

[12] J. Mohmmed, and N. Mahmood, “Evaluation the Mechanical Properties of Shot Peened TIG Welded Aluminum Sheets”, *Journal of Engineering, Baghdad University*, Vol. 23, no. 4, pp., 79 – 87, 2017.

[13] M. Omar, and H. Soltan, “A framework for welding process selection”, *SN Applied Sciences*, 5, 2020.

[14] M.A. Omar, F.A. Elerian, H.A. Soltan, and M.S. Ghattas, “An Integrated Approach for Welding Process Selection”, *Mansoura Engineering Journal, (MEJ)*, Vol. 43, No. 1, 2018.

[15] B. Benhabib, “Manufacturing Design, Production, Automation, and Integration”, Toronto: Marcel Dekker, 2003.

[16] S. Kalpakjian, S.R. Schmid, S.R. and K.S. Vijay Sekar, “Manufacturing Engineering and Technology”, *7th Edition, 14, Singapore: Pearson Education South Asia Pte Ltd*, 2014.

[17] M.P. Groover, “Fundamentals of Modern Manufacturing Materials, Processes, and Systems’, *Fifth Edition, USA: John Wiley & Sons*, 2013.

[18] O.B. Annette, “Welding Handbook”, Volume 2, Welding Processes, Part 1. Ninth Edition, American Welding Society (AWS), Miami, 2004.

[19] C.T. Mgonja, “The Effects of Arc Welding Hazards to Welders and People Surrounding the Welding Area”, *International Journal of Mechanical Engineering and Technology (IJMET)*, 8 (3), 2017.

[20] P. Houldcroft, “Which Process, an introduction to welding and related processes and a guide to their selection”, *England: Woodhead Publishing Ltd, Ahington Hall. Abington*, 1990.

[21] L. Jeffus, “Welding Principles and Applications”, *Seventh Edition, 12, USA: Delmar, Cengage Learning*, 2012.

[22] K.G. Swift, and J.D. Booker, “Manufacturing Process Selection Handbook”, *United Kingdom: Butterworth-Heinemann is an imprint of Elsevier*, 2013.

[23] ESAB Publications, Typical Welding Parameters - ESAB 5556HQ, "https://www.esabna.com/euweb/fm_handbook/577fm4_18.htm".

[24] LINCOLN ELECTRIC Publications, Largest Diameter FCAW Wire for Out of Position Welding, "https://www.lincolnelectric.com/enus/support/weldingsolutions/Pages/largestfcaw-wire-out-of-position.aspx".

[25] ESAB Publications, Calculating Filler Metal Consumption, "https://www.esabna.com/euweb/fm_handbook/577fm5_98.htm".

[26] ESAB Publications, Recommended Welding Parameters for Spoolarc Submerged Arc Wires, "https://www.esabna.com/euweb/fm_handbook/577fm6_33.htm".

[27] Wikipedia, Submerged Arc Welding (SAW), "https://en.wikipedia.org/wiki/Submerged_arc_welding".

[28] Canadian Fabricating & Welding Publications, Submerged arc tech tips, "https://www.canadianmetalworking.com/article/welding/is-submergd-arc-welding-the-right-process-for-you".

[29] The Fabricator Publications, 3 ways to boost submerged arc welding performance, "https://www.thefabricator.com/article/arcwelding/3-ways-to-boost submerged-arc-welding-performance".

[30] Arc Machines Publications, Advances in Automatic Hot GTAW (TIG) Welding, "http://www.arcmachines.com/news/case-studies/advances-automatic-hot-wire-gtaw-tig-welding".

[31] Arc Machines Publications, Automated hot wire TIG with positioned for high productivity quality welding, "http://www.arcmachines.com/applications/fixedautomation/automated-hot-wire-tig".

[32] Fabricating and Metalworking Publications, Synchronized Tandem MIG® Process Revealed, "http://www.fabricatingandmetalworking.com/2013/09/synchronized-tandem-mig-process-revealed/".

[33] Weld Guru Publications, Tubular or Flux-Cored Electrodes, "http://weldguru.com/OLDSITE/flux-cored-electrodes.html".

[34] Welding Answers Publications, Deposition Rates for Stick Electrodes, "http://weldinganswers.com/deposition-rates-for-stick-electrodes/".

[35] ESAB Publications, Up to 100% Increased Deposition Rate, "https://www.esab.co.uk/gb/en/automation/process-solutions/saw/saw-ice/high-deposition-rate.cfm".

[36] ESAB Publications, Deposition Data Charts, "https://www.esabna.com/euweb/awtc/lesson9_10.htm".

[37] ESAB Publications, Flux Cored Arc Welding, Gas Metal Arc Welding, and Submerged Arc Welding, "https://www.esabna.com/euweb/awtc/lesson9_13.htm"

[38] Welding experts in "Heavy Engineering Equipment State Company" (HEESCO) in Al – Dura Refinery, Baghdad, Iraqi. http://www.heesco.oil.gov.iq/en/enindex.html.