Mansoura Engineering Journal

Volume 43 | Issue 1 Article 9

6-8-2020

# An Integrated Approach for Welding Process Selection.

Mohamed Omar
*Production Engineering and Mechanical Design Department, Faculty of Engineering, Mansoura University, Mansoura 35516, Egyp*, mohamed_omar@mans.edu.eg

Fatma Elerian
*Production Engineering and Mechanical Design Department, Faculty of Engineering, Mansoura University, Mansoura 35516, Egypt*, fatma2000@yahoo.com

Hassan Soltan
*the Production Engineering and Mechanical Design Department, Faculty of Engineering, Mansoura University, Mansoura 35516, Egypt*, hasoltan@hotmail.com

Magdy Ibrahim
*Production Engineering and Mechanical Design Department, Faculty of Engineering, Mansoura University, Mansoura 35516, Egypt*, magdy_s@mans.edu.eg



Recommended Citation

Omar, Mohamed; Elerian, Fatma; Soltan, Hassan; and Ibrahim, Magdy (2020) "An Integrated Approach for Welding Process Selection.," *Mansoura Engineering Journal*: Vol. 43 : Iss. 1 , Article 9.
Available at: https://doi.org/10.21608/bfemu.2020.94524

Mansoura University
Faculty of Engineering
Mansoura Engineering Journal

# An Integrated Approach for Welding Process Selection

# أسلوب تكاملي لاختيار عملية اللحام

M.A. Omar, F.A. Elerian, H.A. Soltan and M.S. Ghattas

**KEYWORDS:**
*Welding process, FUZZY-AHP, FUZZY-TOPSIS, MCDM*

*الملخص العربي:-* هذا البحث يقدم ويستعرض بحالة دراسية إطار داعم ثنائي الطور لاتخاذ القرار في اختيار نوع عملية اللحام من بين أي عدد من العمليات المقترحة لغرض محدد وتحت ظروف محددة. يقوم الطور الأول باستبعاد العمليات الغير متوافقة تماماً مع التطبيق المطلوب على أساس فئة محددة من المعايير. وبعد ذلك يقوم الطور الثاني باختيار عملية اللحام الأنسب للتطبيق من بين العمليات المتبقية على أساس فئة أخرى مكملة للمعايير. والطور الثاني يدمج طريقتين، الأولي (FUZZY-AHP) والتي تقوم بزنة معايير الاختيار طبقاً للهدف، وتقوم الطريقة التالية (FUZZY-TOPSIS) بترتيب أفضلية عمليات اللحام وتقرر الأنسب من بينهم. ويتضح أن الإطار المقترح يغطي مدي أوسع من المعايير التطبيقية لعمليات للحام وبمرونة وطواعية أكثر. ولذلك فان الإطار المقترح يمكنه بسهولة تناول المشكلات الأكثر تعقيداً لاختيار عمليات اللحام في الصناعة.

***Abstract*— A two-phase decision support framework is presented and experimented with a case study to find the level of preference of any number of welding processes under a variety of welding circumstances. First phase fathoms unapplied/inappropriate welding processes based on a set of exclusion criteria. Second phase decides the best welding process amongst those remaining according to a set of selection criteria. The second phase is an integration of two methods, FUZZY-AHP which weights the selection criteria with the goal, and FUZZY-TOPSIS which ranks such criteria and gets most suitable welding process. The proposed framework covers a wider range of practical welding criteria with more flexibility and amenability; thus, making it possible to be simply applied in the complex industrial problem.**

## NOMENCLATURE

*Received: 26 July2017 - accepted: 9 January 2018*
*M.A. Omar is with Production Engineering and Mechanical Design Department, Faculty of Engineering, Mansoura University, Mansoura 35516, Egypt (e-mail: mohamed_omar@mans.edu.eg).*
*F.A. Elerian is with Production Engineering and Mechanical Design Department, Faculty of Engineering, Mansoura University, Mansoura 35516, Egypt (e-mail: eng_fatma2000@yahoo.com).*
*H.A. Soltan is with the Production Engineering and Mechanical Design Department, Faculty of Engineering, Mansoura University, Mansoura 35516, Egypt (e-mail: hasoltan@hotmail.com).*
*M.S. Ghattas is with the Production Engineering and Mechanical Design Department, Faculty of Engineering, Mansoura University, Mansoura 35516, Egypt (e-mail: magdy_s@mans.edu.eg).).*

| | | | |
|---|---|---|---|
| AHP | Analytic Hierarch Process | IS | Induction soldering |
| BCW | Butt cold welding | LBW | Laser beam welding |
| BZW | Braze welding | L-MIG | Laser metal inert gas |
| CD-SW | Capacitor discharge stud welding | MAG | Metal active gas |
| CEXW | Co-extrusion welding | MCDM | Multi criteria decision making |
| DB | Dip brazing | MIG | Metal Inert gas |
| DCW | Drawing cold welding | MMAW | Manual metal arc welding |
| DFB | Diffusion brazing | PAW | Plasma arc welding |
| DFS | Diffusion soldering | PE-TIG | Penetration enhanced |
| DFW | Diffusion welding | P-MIG | Plasma metal inert gas |
| DS | Dip soldering | RB | Resistance brazing |
| EBW | Electron beam welding | RLW | Roll welding |
| EBW-NV | Electron beam welding-non-vacuum | RPW | Resistance projection welding |
| EBW-V | Electron beam welding-vacuum | RS | Resistance soldering |
| EGW | Electro gas welding | RSEW | Resistance seam welding |
| ESW | Electro slag welding | RSW | Resistance spot welding |
| EXW | Explosive welding | SAW | Submerged arc welding |
| FB | Furnace brazing | SMAW | Shielded metal arc welding |
| FCAW-G | Flux cored arc welding-gas | SW | Stud welding |
| FCAW-S | Flux cored arc welding-shielded | TB | Torch brazing |
| FGW | Forge welding | THW | Thermite welding |
| FRW | Friction welding | TIG | Tungsten inert gas |
| FS | Furnace soldering | TOPSIS | Technique for Order Preference by |

| | | | |
|---|---|---|---|
| | | | Similarity to Ideal Solution |
| FSW | Friction stir welding | TS | Torch soldering |
| FW | Flash welding | USW | Upset welding |
| GTAW | Gas tungsten arc welding | UV | Ultra violet |
| GW | Gas welding | UW | Upset welding |
| HFW | High frequency welding | ICW | Indentation cold welding |
| IB | Induction brazing | | |

## I. INTRODUCTION

Welding is a manufacturing process used to produce an assembly or structure from parts or structural elements. There are more than 40 known welding methods applied in industry. Welding method selection depends on the manufacturing engineers experience when they are dealing with applications that they are familiar considering a few factors, mostly the discontinuity (an element of quality) and cost which may be insufficient while there will be many welding methods equally fulfill the required product [1, 2]. Therefore, specific systems should be developed for helping engineers in welding method selection depending on knowledge bases that contain all problem factors.

As the welding processes are alternatives and the welding factors are criteria, the problem becomes a multi-criteria decision-making problem. Thus, MCDM methods such as TOPSIS, AHP and their FUZZY versions become relevant as seen later in this paper.

There are a lot of work done to solve this selection problem such as Darwish et al. [1] who developed a knowledge-based system for determining the most suitable welding method for a given circumstances and they experimented 30 welding methods. Their system includes the factors of product type, material type, and material thickness, method of use, quality level, joint type and welding position. Their system needs to prescreen to the welding methods. Brown et al. [3] introduced a methodology for determining the most suitable joining technology where the methodology is intended to highlight candidate processes that are capable of joining under given conditions; where the selection methodology depends on criteria like joint function (load type and strength), joint technical information (joint configuration and material type), joint spatial information (material thickness and size) and economic factors (production volume and skill required). These criteria are stored in database and implemented in software. Such systems merely introduce candidate welding methods without robust selection.

More robust selection systems were introduced such as Esawi and Ashby [4] who described a methodology for joining method selection implemented in a software; where a search engine isolates the processes that meet design requirements of material, joint geometry and loading where the information about joining processes with respect to each criteria are stored in a database. After getting the isolated processes they are ranked according to relative equipment cost or by production rate; that is more relevant.

There are other methodologies that select among a given number of welding processes for a given application/situation. Jafarian and Vahdat [5] described a knowledge-base-system for determining most suitable welding method for a given circumstances. They used nine important welding processes considering the criteria of operator factor, alloy class, material thickness, capital cost, deposition rate, design application, joint configuration, welding position, equipment portability and filler metal utilization. In this methodology a FUZZY-AHP-TOPSIS method was used to compare between welding methods. This system indicated that GTAW, PAW and EBW are the most suitable welding methods for high pressure vessel. Capraz et al. [6] used AHP and TOPSIS to select a welding method for welding plain carbon stainless steel storage tank. AHP is used to get criteria weights according to experts' opinion and TOPSIS is used for ranking the welding processes. They applied to MMAW, MIG, MAG, GTAW and SAW welding processes.

The remaining of this paper is organized as follows. The welding processes those implemented here are stated in §II. The proposed framework is described and demonstrated in §III. Concluding remarks are presented in §IV. The paper also contains an Appendix.

## II. WELDING PROCESSES

A group of 49 welding processes are considered in this study classified as follows based on the source/cause of coalescence between the welded parts.

- *Pressure Welding Processes*
- *Fusion welding processes*

RSW, RSEW, RPW, HFW, FW, SW, CD-SW.

- *Non-fusion welding processes*

UW, DFW, RLW, EXW, ICW, BCW, DCW, CEXW, FGW, FSW, FRW, USW.

- *Non-pressure Welding Processes*
- *Homogenous welding processes*

SMAW, MIG, FCAW-G, FCAW-S, PE-TIG, TIG, SAW, P-MIG, L-MIG, PAW, EGW, ESW, EBW-V, EBW-NV, LBW, GW.

- *Heterogeneous welding processes*

TB, DFB, DB, FB, IB, RB, BZW, TS, DFS, DS, FS, IS, RS and THW.

## III. SELECTION FRAMEWORK FOR WELDING PROCESS

The proposed framework as explored clearly in Fig. 1 comprises two phases — *exclusion phase* and *selection* phase.

### A. Exclusion Phase

This phase identifies the ***functional candidate*** group of welding processes amongst those submitted first and fathoms the other processes. Thus, the given welding processes are reduced to those meet working circumstances of *nine factors* including are maximum and minimum welded part volume, material type, maximum and minimum joint thickness, production volume, weld position, joint type, applicable joint configuration, weld place, and possible applications.

### B. Selection Phase

In this phase, the welding processes that meet the given nine factors are ranked using FUZZY-TOPSIS method based on only *seven factors* those are welding equipment cost, operator factor, maintenance complexity of welding equipment due to machine structure, surface finish, process preparation, health & safety, and weld discontinuity free.

The MCDM problem necessarily weights/ranks the inherent criteria. Here, FUZZY-AHP method is used for criteria weighting assisted by decision engineer opinions and other information. These weights move to FUZZY-TOPSIS method to decide the preferable welding process.

This framework is programmed in MATLAB environment and it can be introduced as a software for users with such *graphical user interface* that shown in Fig. 2. The user only feeds the information displayed on the shown interface. For each factor the user selects from a pop-up-menu.

The program is constructed to display the most preferable welding processes on solution screen cell while other results are stored internally. First, the user manually inputs the information about relative importance (pairwise comparison matrix) of the seven selection criteria in *criteria weights determination* panel based on AHP Saaty's scale {1/9, 1/8, ..., 1/2; 1, 2, ..., 9}. Other information are also manually inputted following the instructions on the interface.

The necessary information of available welding processes should be collected, arranged, and set as those data samples displayed in the Appendix. This information represents the handmaiden for constructing the built-in database.

The relationships of the welding processes with welding factors are organized from four sources, textbooks, papers, and the websites of international welding companies and the companies that use welding in EGYPT [7]. Refer to Tables 1-11 in Appendix. Tables 2-8 are collected aided with references [8-18]; Table 10 with references [2, 9, 16]; Table 11 with references [7, 9, 10, 12-15, 18-23]. In addition, Tables 9 and 11 are based on Table 1.

The program is applied to a real case having circumstances as welding low carbon steel, butt joint, vertical position, tube to tube configuration, 50 pieces, plumbing application, in site welding, 10 mm thickness and volume $0.07m^3$. Table 12 in Appendix is the pairwise comparison matrix of this case. This matrix and other information are fed manually as shown in Fig. 2. The best welding process for this case is found TB (Torch Brazing) process followed by TIG and SMAW processes as recorded in Appendix, Table 13, which is found very near to the reality as appear from linguistic values of the seven selection criteria.

## IV. Conclusions

This paper introduces a flexible and amenable decision framework for ***welding process selection*** avoiding several shortcomings of others. It filters the submitted processes twice through a sequence of two sets of robust criteria including new ones such as health & safety and system maintenance. This is actuated with an integrated powerful decision-making engine. Thus, it can ensure the right decision of differentiating a wider range of industrial processes whatever the complexity of products and welding processes including recent situations.

Furthermore, this framework can easily accommodate other criteria and evaluation functions since it becomes an inception for portable software.

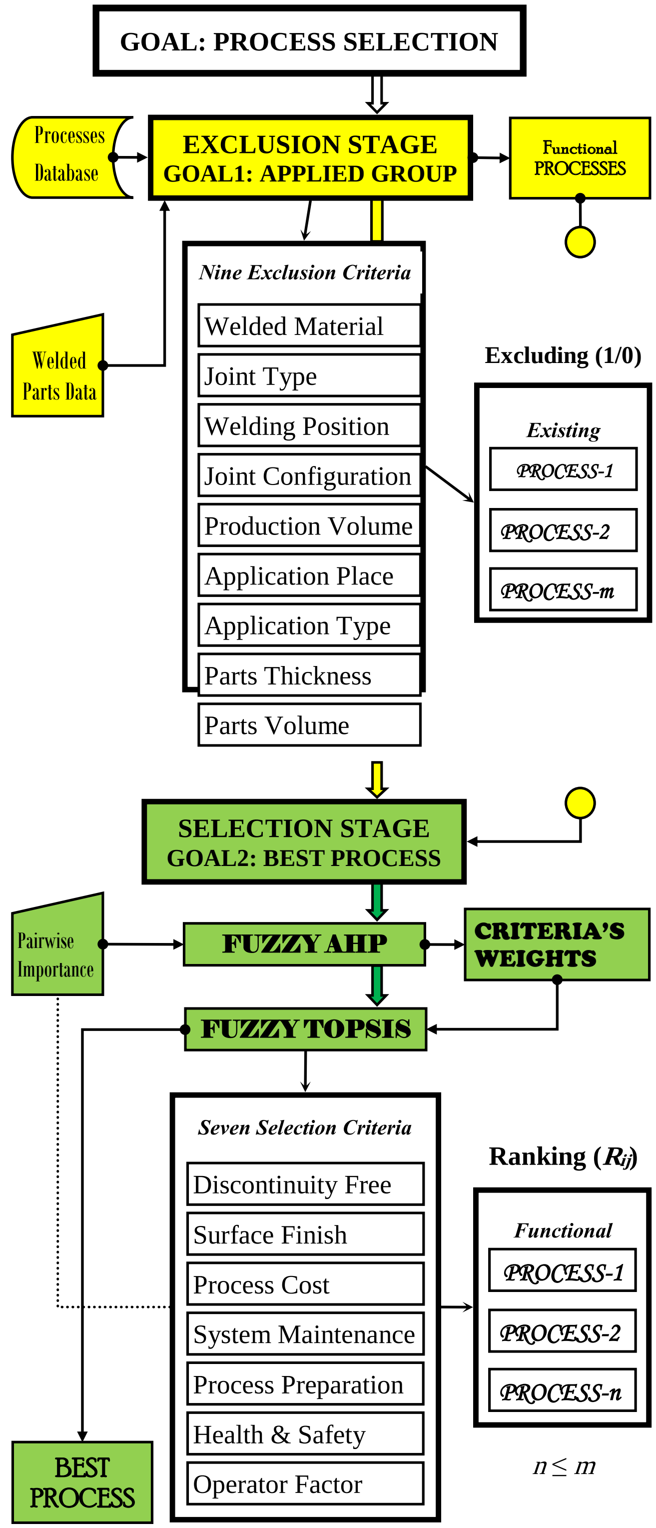


Fig. 1. Proposed framework for welding process selection.

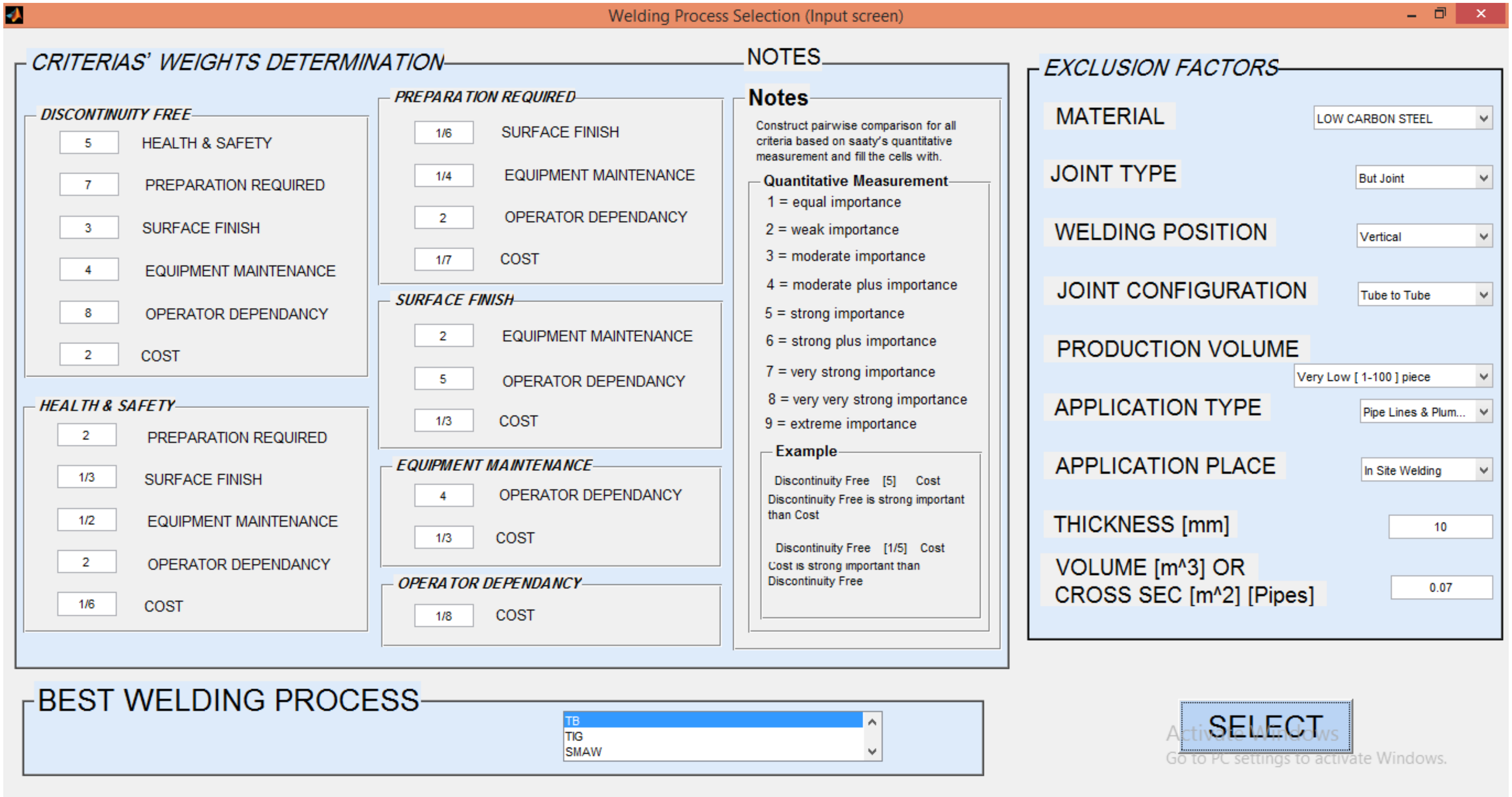


Fig. 2. The interface of the constructed program with input data of the case study.

## Appendix

TABLE 1
SOME GUIDING WELDING COMPANIES.

| NO. | Company | Information |
|---|---|---|
| 1 | Lincoln Electric | Equipment cost & maintenance |
| 2 | The Monty | Equipment cost & welded parts volume |
| 3 | Nelson Stud Welding | Equipment cost |
| 4 | SCIAKY INC | Equipment cost & maintenance |
| 5 | EPB Ltd. | Equipment cost |
| 6 | USA Weld | Equipment cost |
| 7 | The Welders Warehouse | Equipment cost |
| 8 | Image Industries | Equipment maintenance |
| 9 | The Fabricator | Equipment maintenance |
| 10 | Modern Welding | Equipment maintenance |
| 11 | Government of South Australia | Equipment maintenance |
| 12 | Property Maintenance (Job Insider) | Equipment maintenance |
| 13 | DBG | Equipment maintenance |
| 14 | OKUMA | Equipment maintenance |
| 15 | MTI Manufacturing Technology Inc. | Equipment maintenance |
| 16 | T.J. Snow | Welded parts volume |
| 17 | Alumbra | Welded parts volume |
| 18 | Culaser | Welded parts volume |
| 19 | TWI | Welded parts volume |
| 20 | RV Machine Tools | Welded parts volume |
| 21 | Pressure Welding Machines | Welded parts volume |
| 22 | Nabertherm | Welded parts volume |
| 23 | SOHO | Welded parts volume |
| 24 | Wincoo Machine | Equipment cost |
| 25 | NBXIN Chang | Equipment cost & welded parts volume |
| 26 | KIAIND | Equipment cost & welded parts volume |
| 27 | MORAN | Equipment cost |
| 28 | FS Welder | Equipment cost & welded parts volume |

TABLE 2
MATERIALS THAT CAN BE WELDED BY SAMPLE PROCESSES.

| PROCESS | Low Carbon Steel | Mild Steel | Medium Carbon Steel | High Carbon Steel |
|---|---|---|---|---|
| SMAW | Yes | Yes | Yes | Yes |
| MIG | Yes | Yes | Yes | Yes |
| FCAW-G | No | Yes | No | No |
| FCAW-S | No | Yes | No | No |
| PE-TIG | Yes | Yes | Yes | Yes |
| TIG | Yes | Yes | Yes | Yes |

TABLE 3
MAXIMUM AND MINIMUM PART THICKNESS FOR SAMPLE PROCESSES.

| PROCESS | Minimum Thickness (mm) | Maximum Thickness (mm) |
|---|---|---|
| SMAW | 1.6 | 38 |
| MIG | 0.5 | 80 |
| FCAW-G | 1.5 | 12 |
| FCAW-S | 1.5 | 12 |
| PE-TIG | 0.2 | 30 |
| TIG | 0.2 | 10 |

TABLE 4
APPLICABILITY OF SAMPLE PROCESSES TO SOME JOINTS.

| PROCESS | Butt Joint | Corner Joint | T Joint | Lap Joint | Edge Joint |
|---|---|---|---|---|---|
| SMAW | Yes | Yes | Yes | Yes | Yes |
| MIG | Yes | Yes | Yes | Yes | Yes |
| FCAW-G | Yes | Yes | Yes | Yes | Yes |
| FCAW-S | Yes | Yes | Yes | Yes | Yes |
| PE-TIG | Yes | Yes | Yes | Yes | Yes |
| TIG | Yes | Yes | Yes | Yes | Yes |

TABLE 5
APPLICABILITY OF SAMPLE PROCESSES TO WELD POSITIONS.

| PROCESS | Flat | Horizontal (2G) | Horizontal (2F) | Vertical | Overhead |
|---|---|---|---|---|---|
| SMAW | Yes | No | Yes | Yes | Yes |
| MIG | Yes | No | No | No | No |
| FCAW-G | Yes | No | Yes | Yes | Yes |
| FCAW-S | Yes | No | No | Yes | Yes |
| PE-TIG | No | No | Yes | No | Yes |
| TIG | No | No | No | No | Yes |

TABLE 6
APPLICABILITY OF SAMPLE PROCESSES TO PART CONFIGURATIONS.

| PROCESS | Plate to Plate | Bar to Bar | Bar to Tube | Bar to Plate | Tube to Tube | Tube to Plate |
|---|---|---|---|---|---|---|
| SMAW | Yes | Yes | Yes | Yes | Yes | Yes |
| MIG | Yes | No | Yes | Yes | Yes | Yes |
| FCAW-G | Yes | No | Yes | Yes | Yes | Yes |
| FCAW-S | Yes | No | Yes | Yes | Yes | Yes |
| PE-TIG | Yes | No | Yes | No | Yes | Yes |
| TIG | Yes | Yes | Yes | Yes | Yes | Yes |

TABLE 7
APPLICATIONS OF SOME PROCESSES.

| PROCESS | Ship Construction | Bridge Construction | Pressure Vessels | Heavy Machinery | Pipelines/ Plumbing |
|---|---|---|---|---|---|
| SMAW | Yes | No | Yes | Yes | Yes |
| MIG | Yes | No | No | No | No |
| FCAW-G | Yes | No | Yes | Yes | Yes |
| FCAW-S | Yes | No | No | Yes | Yes |
| PE-TIG | No | No | Yes | No | Yes |
| TIG | No | No | No | No | Yes |

TABLE 8
APPLICABILITY OF SAMPLE PROCESSES TO SOME PLACES.

| PROCESS | In Site | Movable Parts | Continuous Welding |
|---|---|---|---|
| SMAW | Yes | Yes | No |
| MIG | Yes | Yes | Yes |
| FCAW-G | Yes | Yes | Yes |
| FCAW-S | Yes | Yes | Yes |
| PE-TIG | Yes | Yes | Yes |
| TIG | Yes | Yes | Yes |

TABLE 9
MAXIMUM PART VOLUME/SECTION AREA FOR SAMPLE PROCESSES.

| PROCESS | VOLUME/AREA (M3 OR M2) |
|---|---|
| RPW | 0.52272 |
| HFW | 5.76 |
| FW | 0.1 |
| UW | 0.001024 |
| DFW | 550.3992324 |
| RLW | 8.55 |
| EXW | 66 |
| ICW | 0.00189 |
| BCW | 0.0009 |

TABLE 10
PRODUCTION VOLUME FOR SAMPLE PROCESSES.

| PROCESS | Very Low | Low | Medium | High | Very High |
|---|---|---|---|---|---|
| SMAW | Yes | Yes | No | No | No |
| MIG | No | No | Yes | Yes | No |
| FCAW-G | No | No | Yes | Yes | No |
| FCAW-S | No | No | Yes | Yes | No |
| PE-TIG | No | No | Yes | No | No |
| TIG | Yes | Yes | No | No | No |

TABLE 11
SAMPLE PROCESSES WEIGHTED RELATIVE TO THE SELECTION CRITERIA.

| PROCESS | System Cost | Operator Factor | System Maintenance | Surface Finish | Preparation | Health & Safety | Discontinuity Free |
|---|---|---|---|---|---|---|---|
| SMAW | V. Low | V. High | V. Low | Med. | Med. | V. High | V. Low |
| MIG | Low | High | High | High | High | V. High | Low |
| FCAW-G | Low | High | High | High | High | High | Low |
| FCAW-S | Low | High | Med. | High | Med. | High | Low |
| PE-TIG | V. Low | Low | Med. | V. High | High | V. High | Low |
| TIG | V. Low | V. High | Med. | V. High | High | V. High | Low |

TABLE 12
PAIRWISE COMPARISON MATRIX OF SELECTION CRITERIA FOR THE CASE.

| CRITERIA | System Cost | Operator Factor | System Maintenance | Surface Finish | Preparation | Health & Safety | Discontinuity Free |
|---|---|---|---|---|---|---|---|
| Equipment Cost | 1 | 8 | 3 | 3 | 7 | 8 | 1/2 |
| Operator Factor | 1/8 | 1 | 1/4 | 1/5 | 1/2 | 1/2 | 1/8 |
| Maintenance | 1/3 | 4 | 1 | 1/2 | 4 | 2 | 1/4 |
| Surface Finish | 1/3 | 5 | 2 | 1 | 6 | 3 | 1/3 |
| Preparation | 1/7 | 2 | 1/4 | 1/6 | 1 | 1/2 | 1/7 |
| Health & Safety | 1/8 | 2 | 1/2 | 1/3 | 2 | 1 | 1/5 |
| Discontinuity Free | 2 | 8 | 4 | 3 | 7 | 5 | 1 |

TABLE 13
THE FIRST THREE PREFERABLE PROCESSES FOR THE CASE APPLICATION.

| PROCESSE PRIORITY | System Cost | Operator Factor | System Maintenance | Surface Finish | Preparation | Health & Safety | Discontinuity Free |
|---|---|---|---|---|---|---|---|
| 1. TB | V. Low | Med. | Low | High | V. High | V. High | High |
| 2. TIG | V. Low | V. High | Med. | V. High | High | V. High | Low |
| 3. SMAW | V. Low | V. High | V. Low | Med. | Med. | V. High | V. Low |

## REFERENCES


[1]. S.M. Darwish, A.A. Tamimi, and S. Al-Habdan, "A Knowledge Base for Metal Welding Process Selection," International Journal of Machine Tools and Manufacture, Vol. 37, No. 7, pp. 1007–1023, 1997.

[2]. M.S. Arvind Jayant, "Use of Analytic Hierarchy Process (AHP) to Select Welding Process in High Pressure Vessels Manufacturing Environement," International Journal of Applied Engineering Research, Vol. 10, No. 8, pp. 5869–5884, 2015.

[3]. N.J. Brown, K.G. Swift, and J.D. Booker, "Joining Process Selection in Support of a Proactive Design for Assembly," Proceedings of the Institution of Mechanical Engineers, Journal of Engineering Manufacture., Vol. 216, No. 10, pp. 1311–1324, 2002.

[4]. A.M.K. Esawi and M.F. Ashby, "Computer-based Selection of Joining Processes Methods, Software and Case Studies," Materials & Design, Vol. 25, No. 7, pp. 555–564, 2004.

[5]. M. Jafarian and S.E. Vahdat, "A Fuzzy Multi-attribute Approach to Select the Welding Process at High Pressure Vessel Manufacturing," Journal of Manufacturing Processes, Vol. 14, No. 3, pp. 250–256, 2012.

[6]. O. Capraz, C. Meran, W. Warner and A. Gungor, "Using AHP and TOPSIS to Evaluate Welding Processes for Manufacturing Plain Carbon Stainless Steel Storage Tank," Archives of Materials Science and Engineering, Vol. 76, No. 2, pp. 157–162, 2015.

[7]. Suzuki Egypt, Six Octobor City, Egypt; GS for Engineering and Construction, Mosorod, Petroleum Zone, Cairo, Egypt.

[8]. P. Houldcroft, *Which Process?*, Abington Publishing, 1990.

[9]. K.G. Swift and J.D. Booker, *Manufacturing Process Selection Handbook*, Butterworth-Heinemann, 2013.

[10]. AWS, *Materials and Applications*, Part I, Eighth Miami: American Welding Society, 1996.

[11]. C.L. Jenney and A. O'Brien, *Materials and Applications*, Part I, American Welding Society, Vol. 1, 2011.

[12]. C.L. Jenney and A. O'Brien, *Welding Processes*, Part I, American Welding Society, Vol. 1, 2011.

[13]. C.L. Jenney and A. O'Brien, *Welding Processes*, Part II, Vol. 1, 2011.

[14]. A.O.C. Jenney, *Welding Science and Technology*, American Welding Society, 2011.

[15]. Luvata, *Brazing Handbook*, American Welding Society, 2006.

[16]. J. Bralla, *Design for Manufacturability Handbook*, McGraw-Hill Professional, 1998.

[17]. B.L. Alia, R.L. Alley, D. Leroy, T.A. Siewert, S. Liu, and G.R. Edwards, *Welding Brazing and Soldering*, American Society for Metals, Vol. 6, 1993.

[18]. T. Webber, T. Lieb, and J. Mazumder, *Welding Fundamentals and Processes*, American Society for Metals, Vol. 6A, 2011.

[19]. Apprenticeship and Industry Training, *(Welder) Submerged Arc Welding*, Minister of Innovaion and Advanced Education, Alberta, 2014.

[20]. C.T. Dawes, *Laser Welding: A Practical Guide*, Abington Publishing, 1992.

[21]. K. Weman, *Mig Welding Guide*, Woodhead Publishing, 2006.

[22]. M. Harris, *Welding Health and Safety: A Field Guide for OEHS Professionals*, AIHA Press, Virginia, 2002.

[23]. J. Blunt and N.C. Balchin, *Health and Safety in Welding and Allied Processes*, CRC Press, 2002.