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Using AHP and TOPSIS to evaluate welding processes for manufacturing plain carbon stainless steel storage tank

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ABSTRACT

Purpose: In the plain carbon stainless steel storage tank manufacturing industry, there are many types of welding processes used. When selecting the most appropriate welding process is usually done intuitively by the manufacturer depending on its own pre-experiences or common applications in similar companies. However, this approach has a shortsighted view since it generally ignores many conflicting criteria effecting the suitable welding process selection. To overcome this problem, this study aims to evaluate important criteria and alternative welding processes by using some of multi-criteria decision-making approaches to come up with better manufacturing decisions.

Design/methodology/approach: This study uses a combined methodology of Analytical Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Since both of these techniques require experts' contributions, a group meeting is held with the experts from academia and industry.

Findings: The study identified the important criteria for welding selection process in storage tank manufacturing. With the help of experts in the domain, both weights of decision criteria and ranking of alternative welding processes were determined.

Research limitations/implications: Since the techniques used in the study depend on expert's contribution, the expert knowledge on the welding process is critical. When the expert changes the resulting decision may also change. Therefore, the selection of the expert(s) must be done carefully.

Practical implications: The findings of the study are valid for the specific case of the storage tank manufacturing. The study helps manufacturers to understand the framework of welding process selection and make them aware of various techniques (e.g., AHP and TOPSIS). The approach may also be welcomed by other welding applications.

Originality/value: The main contribution of the study is mostly on the practical side. To the authors' best knowledge, this paper is one of few studies investigating the selection of welding process for a plain carbon stainless steel storage tank manufacturing. It may help to increase the attention of researchers on multi-criteria decision-making applications in the welding field.

Keywords: Welding; Multi-criteria decision making; AHP; TOPSIS

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

According to ISO 4063, there are more than 90 different known types of welding processes. Welding is used extensively in all sectors for manufacturing products in a big range from earth moving equipment to aerospace equipment. They can be generally categorized as arc welding, gas welding, resistance welding, energy beam welding and solid-state welding. Every welding method has its own advantages and disadvantages against each other.

The selection of suitable welding process among the available alternatives for a given engineering application becomes an important decision. The selection decision is a multi-criteria decision making problem because it requires to take into account multiple and conflicting criteria such as cost, availability of welding equipment, welding position, appearance of the finished product etc.

So far not many papers about multi-criteria decision-making tools to select the welding process for specific applications have been published [1-8]. In this study, the study carried out by Capraz et al. [2] has been further extended through investigating the views of experts from academia and industry. Meanwhile, a group decision-making process has been practiced. The main contribution of the study is mostly on the practical side. To the authors' best knowledge, this paper is one of few studies investigating the selection of welding process for a plain carbon stainless steel storage tank manufacturing. It may increase the attention of researchers on multi-criteria decision-making applications in the welding field.

The rest of paper is organized as follows. In section 2, AHP and TOPSIS methods are briefly introduced. Section 3 presents the application. In section 4 the conclusions are presented along with some future research suggestions.

2. Description of multi-criteria decision making tools used

2.1. Analytic hierarchy process (AHP)

AHP developed by Thomas L. Saaty during 1970s, is one of the frequently used multi-criteria decision making methods. It has been designed for solving complex problems involving multiple and conflicting criteria. AHP decomposes the complex decisions in a hierarchical structure. The hierarchy involves three elements: the objectives, sub(criteria) and alternatives [9,10]. In recent years, a wide range of papers related to AHP has been published [11,12]. Please refer to Saaty [9] and Saaty and Vargas [10] for details of AHP.

The application steps of AHP are as follows [9,10]:

Step 1. Model the decision problem in a hierarchical structure considering the decision goal, the alternatives for achieving the goal, and the criteria for evaluating the alternatives.

Step 2. Generate pairwise comparisons among the elements of the hierarchy at each level.

Step 3. Determine relative importance or weights of the criteria and alternatives at each level.

Step 4. Check consistency ratio of the pairwise comparisons for the criteria and alternatives.

Step 5. Perform hierarchical analysis to obtain the final results.

Step 6. Make a final decision based on the results.

The main characteristic of AHP is that it is based on pairwise comparison, which is based on Saaty's 1-9 scale given in Table 1. Here, a score of 1 indicates equal importance between the two elements and a score of 9 indicates the extreme importance of one element over another element in a pairwise comparison [9,10].

Table 1.
Numerical ratings for pairwise comparisons

Intensity of Importance	Definition
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values between the two adjacent judgments
Reciprocal	If activity *i* has one of the above numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*

2.2. Technique for order preference by similarity to ideal solution (TOPSIS)

TOPSIS, developed by Hwang and Yoon [13], is a well-known multi-criteria decision making tool. Its objective is to find an alternative that has the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS). In the literature, the TOPSIS method has been successfully applied in several areas [14].

The application steps of TOPSIS are as follows [13,15]:

Step 1. Identify the evaluation criteria.
Step 2. Evaluate each alternative with regard to each criterion.
Step 3. Create a decision matrix consisting of alternatives and criteria.
Step 4. Normalize the decision matrix.
Step 5. Calculate the weighted normalized decision matrix.
Step 6. Determine PIS and NIS.
Step 7. Calculate distance ($S_i^*$and S_i^-) of each alternative from PIS and NIS, respectively
Step 8. Calculate the closeness coefficient (CC_i) of each alternative.
Step 9. According to CC_i, the ranking order of all alternatives can be determined.

2.3. Proposed methodology

The proposed methodology for selecting the welding process involves a combination of AHP and TOPSIS methods. Before applying the proposed methodology, initially, a group meeting consisting of 5 experts with a combined experience from academy and industry and a moderator was organized. The decision problem and the methods to be used were explained to the group members by the moderator. Later, the group members discussed and identified the alternative welding processes and the criteria to be used for evaluating alternative welding types. As a result of this meeting, the proposed AHP-TOPSIS models were structured. AHP was used to calculate the criteria weights while the TOPSIS was used to rank the alternatives.

In AHP, all possible pairwise comparisons among criteria were discussed within the group under the management of the moderator until the consensus was reached. Then, a pairwise comparison matrix was generated in order to use for AHP calculations as given in Section 2.1. Criteria weights were reached. For situations where the consistencies are below the acceptable level, associated pairwise comparisons were re-discussed and revised within the group.

After all criteria weights were determined using SuperDecisions® Software, evaluation scores for alternatives based on each decision criterion were allocated individually by each expert. The arithmetic means of these scores were used during the calculation of the TOPSIS method. Finally, after applying the steps of the TOPSIS method as given in Section 2.2., the ranking list of alternative welding processes was found and the best welding process type for the case was selected.

3. Application

3.1. Product under investigation

The application of the methodology was carried out in a medium scale company located in Denizli, Turkey. It produces solid, liquid, and gas fueled hot water boilers, steam boilers, thermal oil boilers, pressured or non-pressured tanks, systems of hydrophore and cogeneration. Figure 1 depicts the storage tank considered in this study. It is usually manufactured using low carbon non-alloyed structure steel, or pressure steels.

During the expert group meeting, considering the capabilities of the case company, the experts agreed upon that 5 welding processes may be used for the sample tanks given in Figure 1: Manual Metal Arc Welding (MMAW), Metal Inert Gas (MIG), Metal Active Gas (MAG), Gas Tungsten Arc Welding (GTAW) and Submerged Arc Welding (SAW). They are briefly explained as follows. MMAW is one of several fusion processes which create an electric arc between an electrode and the base material. It can be used either direct or alternating current, and consumable or non-consumable electrodes. The melted welding bead is usually protected by shielding gas, or slag. The electrode type and properties should be suitable depend on kind of base materials.

Fig. 1. The general view of a storage tank produced with fusion welding methods

GMAW is an arc welding which needs consumable electrode and a shielding gas to be continuously fed into. GMAW is also commonly known as MIG and MAG. GMAW can be applied in all positions, and produces high quality welds. Equipment needed by GMAW can be used both manually and/or automatically. The main gases used in GMAW to protect the welded area from the contaminants in the atmosphere are Argon, Helium, and Carbon Dioxide [16].

GTAW depends on the use of a non-consumable tungsten electrode which must be protected by an inert gas. This welding type is also known as Tungsten Inert Gas welding (TIG). Welding creates an arc between the tip of the electrode and the work piece to melt the metal to be welded. A filler metal can also be used depending on the thickness of welded materials. A gas shield is needed to protect the electrode, and welds pool thus providing the required arc characteristics. GTAW is especially utilized when thin metals are welded. It can be used for a wide variety of metals and applications, such as aluminium, copper, brass, magnesium, titanium, high alloy metals, and its alloys [17].

SAW is similar to GMAW welding. SAW uses a flux to generate protective gases and slag. It is also needed to add alloying elements to the weld pool. A shielding gas is not required. A thin layer of flux powder is placed on the work piece surface before welding starts. After welding, the remaining fused slag layers can be removed easily. SAW is generally suited to the longitudinal and circumferential butt welds required for the manufacture of line pipe and pressure vessels [18].

3.2. Criteria for evaluating the welding types

Through the literature analysis [1] and the experts' views, we determined the following criteria (Cs) which influence the decision on selecting the suitable welding process.

C1. Cleaning difficulty after welding (Easier is better)
C2. Ease of automation (Easier is better)
C3. Energy requirement (Less energy requirement is better)
C4. Environmental effects (Lower is better)
C5. Flexibility related to welding position (More is better)
C6. Product's look after welding (Inside where the medium is stored and hygienic and standards have to be met; and the outside where the expectations are more aesthetical. However experts agreed that two issues can be merged into a single criterion since both of them affect each other's quality).
C7. Setup complexity prior to welding (Less is better)
C8. Speed of welding process (Quickest is the best)
C9. Use of consumables (Less consumables requirement is better)
C10. Welder's skill needed (Less is better)
C11. Work safety level (Low risk is better)

3.3. AHP and TOPSIS application

For determining both weights of decision criteria and the ranking list of alternative welding process, a group decision making process was practiced. The group of experts included an academician who is an expert on welding processes, an R&D director, a production engineer, a sales engineer and a welder who work at the firm. The study was carried out according to the approach stated in Section 2.3. As a result of AHP, the weights of each criterion, ranking of the criteria and the related consistency ratio were found and presented in Table 2.

From Table 2, welder's skills needed (C10) is determined as the most important criterion (weight = 0.2376) while energy requirement (C3) is determined as the least important criterion (weight = 0.0199)

The criteria weights in Table 2 are used in TOPSIS to rank welding process types and select the best one. Here each expert responded to evaluate alternatives with respect to each criterion based on a 1-100 scale in which 1 point stands for the worst performance while 100 points stands for the best performance score. Further, arithmetic mean of these scores has been taken and used for TOPSIS calculations. The distance of each alternative from the positive ideal (S_i^*) and the negative ideal solutions (S_i^-) and the closeness coefficient (CC_i) of each alternative are summarized in Table 3.

Table 2.
The weights of criteria

Criteria	Weight	Ranking	Consistency Ratio
C1	0.0969	5	0.09374 (Acceptable)
C2	0.0443	8	
C3	0.0199	11	
C4	0.0424	9	
C5	0.1238	4	
C6	0.1263	3	
C7	0.0763	6	
C8	0.0568	7	
C9	0.0246	10	
C10	0.2376	1	
C11	0.1511	2	

Table 3.
The calculation of the positive and the negative ideal solution distances and the closeness coefficient

Welding Processes	S_i^*	S_i^-	CC_i	Normalized CC_i	Rank
MIG	0.0440	0.0538	0.5501	0.2469	2
TIG	0.0529	0.0358	0.4040	0.1813	4
MMAW	0.0826	0.0167	0.1683	0.0756	5
SAW	0.0544	0.0619	0.5321	0.2388	3
MAG	0.0439	0.0591	0.5737	0.2574	1

As Table 3 indicates, according to normalized CC_i values, the best welding process is found be MAG for the case study. MIG is determined as the second most suitable welding process.

4. Conclusions

This paper mainly focused on performing a combined methodology of AHP and TOPSIS to select the best welding process type when manufacturing a plain carbon stainless steel storage tank. The main contribution of the study is mostly on the practical side. In a way, it mimics the intuitively handled decision making process in the case firm and converts it into an organized approach. The study may contribute to the increased use of multi-criteria decision-making approaches in various manufacturing processes.

Additional information

Selected issues related to this paper are planned to be presented at the 22nd Winter International Scientific Conference on Achievements in Mechanical and Materials Engineering Winter-AMME'2015 in the framework of the Bidisciplinary Occasional Scientific Session BOSS'2015 celebrating the 10th anniversary of the foundation of the Association of Computational Materials Science and Surface Engineering and the World Academy of Materials and Manufacturing Engineering and of the foundation of the Worldwide Journal of Achievements in Materials and Manufacturing Engineering.

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