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The Use of the Weighted Ishikawa Diagram in the Assessment of the Quality of the TIG Manual Welding Process

Abstract: The article aims to present the practical use of an Ishikawa diagram in the quality management concerning a selected welding process. The first part of the study describes the TIG welding process and discusses the characteristic of a selected tool. The following part presents the Ishikawa diagram and the division into individual groups of elementary reasons in relation to the welding process subjected to analysis.

Keywords: quality assessment, Ishikawa diagram, welding technology, TIG method

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Introduction

The past century has seen dramatic changes in many industrial sectors. A significant increase in the production and the use of metal alloys, technological development in the heavy industry, considerable emphasis given to the quality and efficiency of production processes as well as fierce competition have forced companies to implement significant corrections in inspection and monitoring systems. A key issue is the development of modern tools enabling relatively easy and effective control over performed tasks. Particular attention has been paid to the elimination of errors arising at various stages of product life - from the selection of materials through manufacturing to the operation of the product. The above-named progress has also influenced welding processes. The past century has seen the development of many new welding processes and the improvement of already existing ones. Because welded joints usually transfer significant loads, their inspection is very rigorous. A wide range of destructive and non-destructive tests is used to prevent potential damage and accidents, which is particularly important in terms of human safety. Preventing the formation of welding imperfections is more effective than the repair of damaged welds, enabling the reduction of repair-related costs. The analysis of a selected welding process could produce very favourable results and demonstrate the effectiveness of commonly used quality assessment tools.

TIG

The tungsten inter gas welding process (TIG) also known as gas tungsten arc welding (GTAW), wolfram inter gas welding (WIG) or Heliarc welding (in English language publications). The last name was invented by Russell

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Meredith, who improved the process in 1941 [1] and named it Heliarc as he used arc generated by the tungsten electrode and helium as the shielding gas.

The quality, including the mechanical properties, of welded joints can be viewed as the function of certain material and process variables. Material variables include, among other things, types of welded materials (in terms of similar and dissimilar joints), types of filler metals, types of shielding gases, the purity of shielding gases and welder's skills [2]. In turn, process variables include such parameters as the voltage of welding current, the welding rate or the shielding gas flow rate [3]. The TIG process (pulsed current welding) involves the use of such parameters as peak welding current, basic welding current, impulse frequency and the welding rate [4]. Other tests revealed that the quality (including the mechanical properties) of the welded joint is primarily affected by the proportion of the time of a current impulse to the time of the entire current cycle. The aforesaid ratio, enabling the obtainment of the favourable quality (including mechanical properties) of the welded joint should amount to 40% [5]. Other tests involved such parameters as [6] arc length, the travel rate of the welding torch, welding current, the shielding gas flow rate, the value of the electrode tip angle and the chemical composition of gas. Authors of certain publications stated that the primary factor affecting the quality of the welding process was welding current [7]. Other authors indicated specific parameters such as the distance between the electrode and the weld pool amounting to 1 mm, a welding torch travel rate of 130 mm/min, a welding current of 140 A and an arc voltage of 12 V [8].

The TIG process was used to develop an Ishikawa diagram, i.e. a tool which makes it possible to identify the effect of welding parameters on the welding process.

Ishikawa diagram as a process quality assessment tool

An Ishikawa diagram was first used in Japan in Sumitomo Electric. The diagram was developed by Kaoru Ishikawa, a Tokyo University professor, who in 1962 published the assumptions of the diagram [9] (although Japanese sources refer to the year 1956 [10]). Initially, the diagram was only used to perform the qualitative analysis of the production process (detection of reasons for defects), yet it soon appeared useful in other areas. The diagram, successfully used also in administration, project management and functionality analysis, constitutes the graphic representation of the correlation between results and possible reasons [11].

The diagram constitutes the image of analysis performed from general to particular. Groups of primary reasons can be determined arbitrarily by an assessment team, yet they are more often adopted in accordance with one of

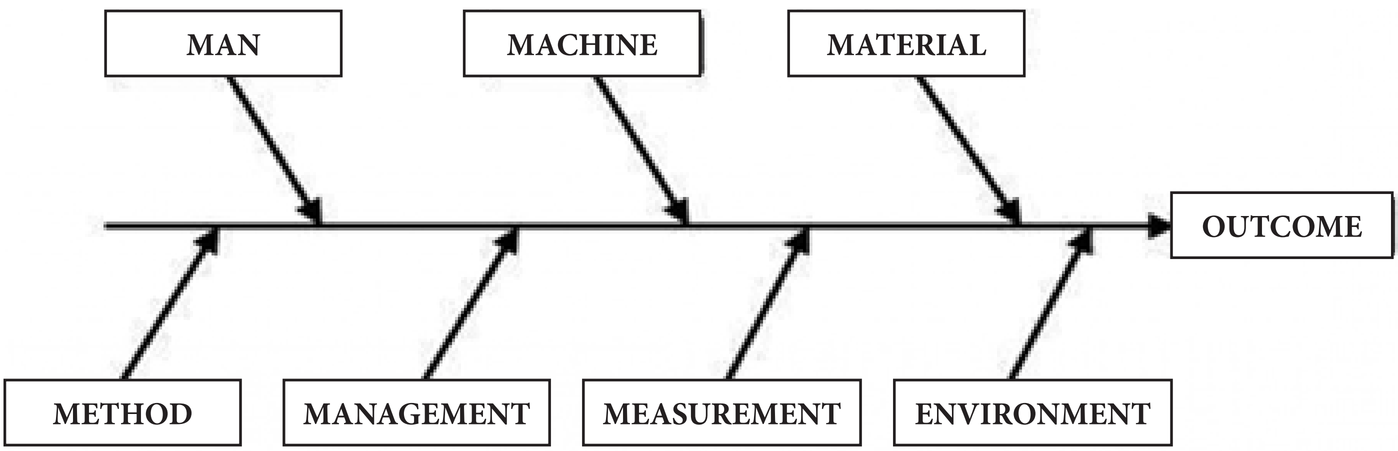

Fig. 1. Exemplary Ishikawa diagram in the 6M+E system

developed standard systems. Primary (elementary) reasons are placed in individual groups. As a result, the structure of the diagram is hierarchical. In the Ishikawa diagram the procedure applied to search for reasons of a previously identified outcome includes the identification of a problem, the determination of the main categories of reasons (selection of reasons having the greatest impact on a possible problem) and the identification of elementary (primary) reasons [11]. Figure 1 presents the system of reasons referred to as 6M+E (or, sometimes, as 5M+2M). The above-presented designation signifies the consideration of elementary reasons within the area of 7 primary reasons (see Figure 1). However, it is possible to ultimately distinguish as many as eight primary reasons, indicated in various reference publications: the effect of a man (Man, Manpower), the effect of a machine (Machine), the effect of a material (Material), the effect of a method (Method), the effect of management (Management), the effect of measurement (Measurement), the effect of environment (Environment, Mother Nature, Milieu), the effect of maintenance (Maintenance) and the effect of finance (Money).

The effect of Man involves such elements as qualifications, habits, work satisfaction, seniority as well as momentary conditions or routine. The scope of the second primary reason, i.e. the effect of Machine, includes technical conditions, service life, efficiency, technical level (state-of-the-art), precision and current work conditions (including the position). The aforesaid category also includes the issue of licence. Another category is the effect of Material, including an input raw material, auxiliary materials, elements and components as well as substitutes. The fourth group, i.e. the effect of Method, involves procedures, instructions, specifications, standards, rules of conduct and technology. The effect of Management, i.e. the fifth group includes the organisation and culture of work, organisational structure, work shifts and work conditions as well as personnel management (including pressure connected with project implementation or training). The last of the traditional groups is the effect of Environment, including physical (temperature, pressure, humidity, shielding gas flow rate and radiation), chemical (chemical composition, concentration, flammability and taste) as well as the ergonomic conditions of environment (dust, lighting and noise). These traditional parameters (composing the 5M+E system [11]) are supplemented with three additional groups of reasons. The first of the three additional groups is the effect of Measurement, including, among other things, the method of measurement (including the effect of lighting and external conditions), the interpretation of measurement results, the correctness of measurements (including the precision of indications and the tiredness of persons performing a given measurement) etc. [12]. The second group is the effect of Maintenance, where the elementary reasons include methods of maintenance, work monitoring and repair planning [13]. The last of the three additional groups is the effect of Money, including the necessity of purchasing cheaper materials or substitutes, the elimination of technical inspections or the reduction of their frequency as well as the elimination of training courses or the reduction of their frequency [14].

The above-presented description depicts the Ishikawa diagram in the technological aspect. In addition to that, there are [15] marketing (8P) and service (4S) approaches. It is also important that the traditional Ishikawa diagram constitutes a tree of relationships (tree diagram) presenting relations between reasons subjected to analysis and their hierarchy. The diagram presents a group of reasons, yet it does not identify their effect on a problem subjected to analysis. Therefore, in such a form, the diagram is a qualitative tool only. However, the weighted Ishikawa diagram [16] is of the quantitative nature. The idea of the weighted Ishikawa diagram is based on the presentation of qualitative information concerning a given problem and quantitative analysis, decisive for the significance of individual reasons against the background of remaining ones. As regards the traditional diagram, the indication of the most or least important problem requires the performance of analysis and group discussion. The concept of the weighted Ishikawa diagram eliminates such a need. As a result, it is possible to avoid subjectivity or the effect of the force of character on the assessment of individual reasons on an outcome subjected to analysis. Figure 2 presents the exemplary application of the weighted Ishikawa diagram.

The methodology of the development of the weighted Ishikawa diagram includes the performance of tasks involving the definition of the set of groups of primary reasons (or the selection of one of the standard types of the diagram) and, next, of elementary reasons for each of the group of primary reasons. At the subsequent stage, weight functions of the groups of reasons and elementary reasons are determined using the method of pair comparison. The final phase involves the identification of absolute values of elementary weight functions defining their significance degree against the background of the remaining reasons of this type (by referring their weight functions to the weight functions of the groups of primary reasons). Such an approach enables the identification of factors the content of which in the formation of an analysed outcome is the greatest. In the article, the concept of the weighted Ishikawa diagram was used to identify factors significantly affecting the TIG method-based welding process.

The assumption adopted in the article is the use of the complete technological weighted Ishikawa diagram in the 8M+E system (or 5M +4M).

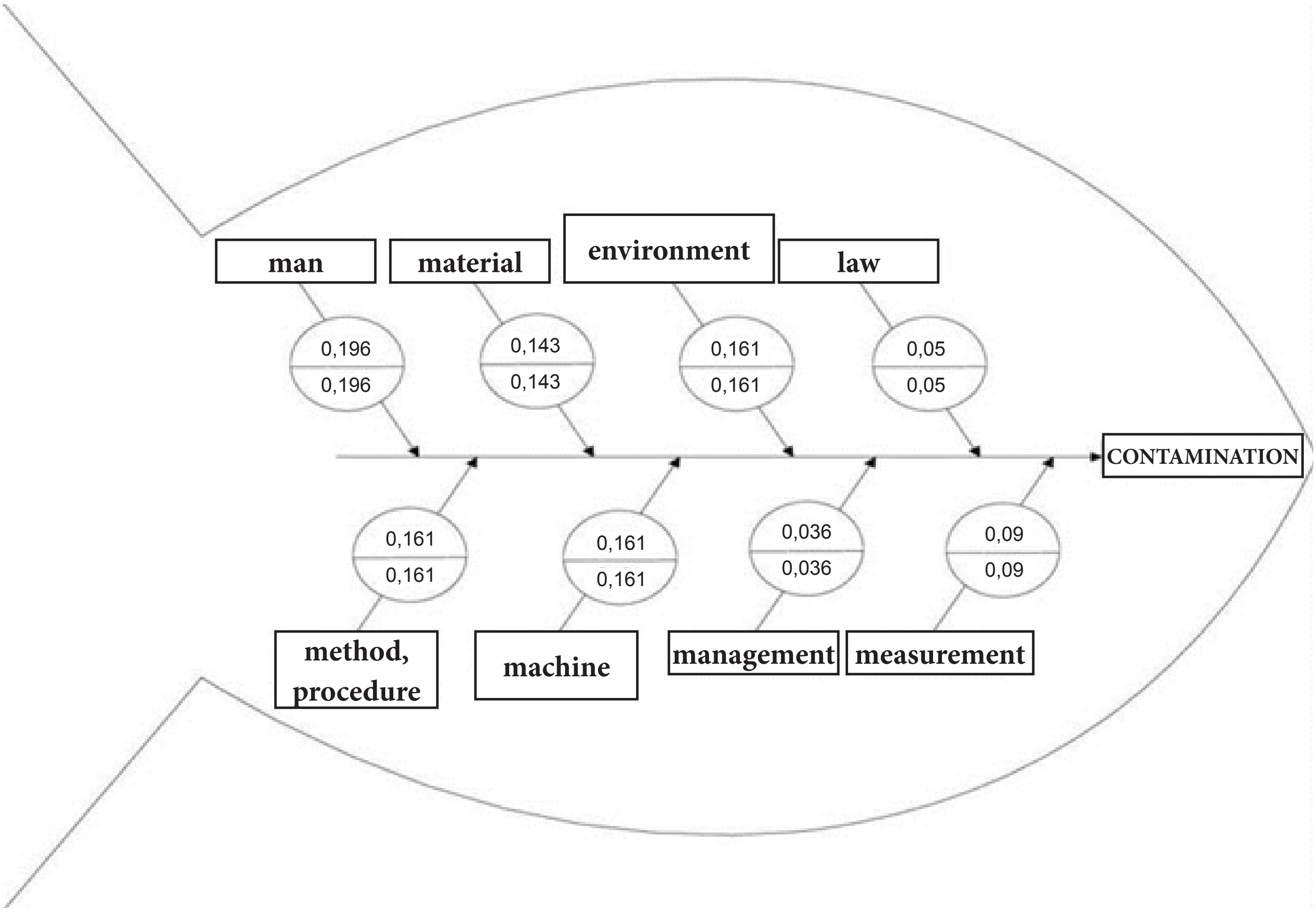

Fig. 2. Examples of the weighted Ishikawa diagram in the 6M+E system [17]

Weighted Ishikawa diagram for the TIG welding process

The conclusion based on the above-presented overview of factors affecting the course of the TIG welding process is that parameters affect the properties (e.g. mechanical properties) of the welded joint in various ways. The Ishikawa diagram concerning the TIG welding process (selected as an exemplary welding process) is presented in Figure 3. The analysis of the problem shows that a significant number of factors variously affect the process. For instance, based on practical experience, it is possible to demonstrate that the overly small size of the threshold gap worsens the quality of the welded joints (including its mechanical properties), whereas the excessively large size of the threshold gap could preclude the obtainment of the welded joint. Therefore, the threshold gap can be treated as an example of a parameter playing an important role in the formation of the welded joint and directly translating into its mechanical properties (including strength).

The complete preparation of the Ishikawa diagram with elementary reasons requires including several more elements connected with the TIG welding process. The first element is the electrode diameter, whereas the second one is the shape of the electrode tip. In relation to pre-set current, the tungsten electrode having a greater diameter will be characterised by longer service life but also by the less favourable welding arc initiation. Excessively high current will lead to the melting of the electrode tip, whereas overly low current will be responsible for arc burning instability. For this reason, to provide the high temperature and stability of arc, the electrode diameter is usually selected with certain excess [18,19]. Another parameter is the diameter of the filler metal wire – as a rule, selected on the basis of the thickness of material being welded [20] and on the melting rate. The next group of factors is connected with welding gases (on the side of arc and the weld pool as well as on the side of shielding and the weld root). If, during the welding process, the shielding gas flow is continuous and uniform, the shielding of the weld pool and, consequently, the quality of the welded joint is improved. However, it should be noted that, during the welding process, the weld may undergo oxidation on its root side. As a result, the weld will be characterised by porosity and lower strength [21]. For this reason, it is necessary to ensure the uniform flow of the shielding gas fed on the weld root side [22, 23]. The final group of factors includes current-related parameters. It should be noted that welding current is correlated with the welding rate and voltage. Usually, only welding current is adopted as an input variable [24, 25]. The welding rate is the function of thickness. Therefore, the thickness of sheets/plates subjected to welding is also regarded as a factor affecting the quality of the joint [26]. The final version of the weighted Ishikawa diagram (with groups of reasons and elementary reasons) in relation to the TIG manual welding process is presented in Figure 4. The green colour indicates subgroups of reasons within the scope of the Method group. The aforesaid

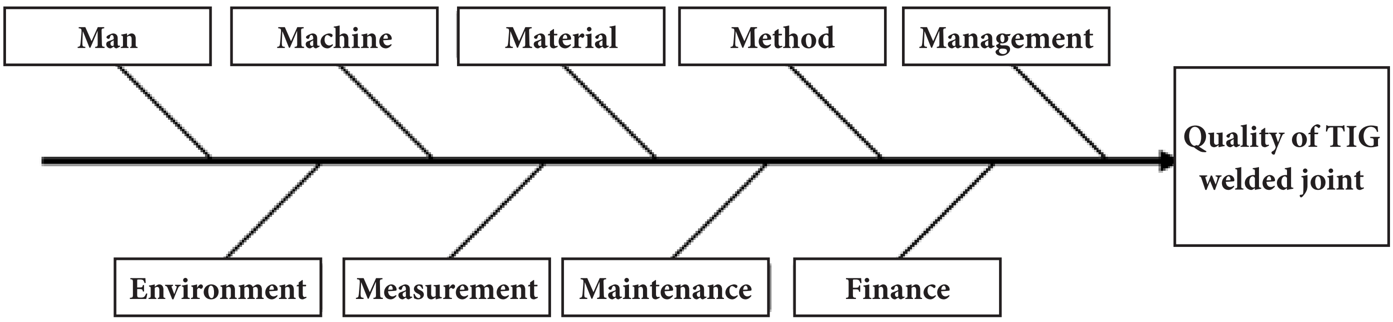

Fig. 3. Exemplary Ishikawa diagram for the TIG manual welding process

subgroups (in the form of partial Ishikawa diagrams) are presented in detail below the main diagram.

The values of weight functions of individual groups of reasons and elementary reasons are identified using the pair comparison method [16]. The method involves the use of the square matrix (to compare pairs of reasons (Fig. 5)). The aforesaid approach increases assessment objectivity as the assessor's task comes down to the comparison of two elements. The same reasons are not subjected to comparison, hence fields located diagonally are excluded from assessment (X). The assessment involves the application of various grade scales. The standardised grade scale used in this article consists of five elements: 0 – definitely less significant, 0.25 – less significant, 0.5 – equivalent, 0.75 – more significant and 1 – definitely more significant. The significance of reasons is assessed in rows. In relation to the first row (Man), the meaning of the first two grades is as follows: 0.75 – effect by Man is more significant than effect by Machine and 0.5 – effect by Man is the same as the effect by Material. The grades located below the diagonal supplement the grades located above the line to 1 (wij = 1 – wji, where i – row number and j – column number). As a result, assessment comes down to the determination of grades above the diagonal.

Grade values are summed up in the rows and, next, standardised so that their sum amounts to 1 (the last two columns). The same method is used in the identification of grades of elementary reasons within given primary groups (upper numeral in Fig. 4); their sum also amounts to 1. After being multiplied by the value of the weight function of the entire group, the above-named grades provide the actual value of the grade of an elementary reason within the entire diagram (lower numeral).

Summary

The above-presented analysis made it possible to precisely assess the significance of individual reasons affecting the quality of the TIG welded joint. It should be noted that the above-presented reasons and their weight functions are of subjective nature because there were determined in relation to a general case on the basis

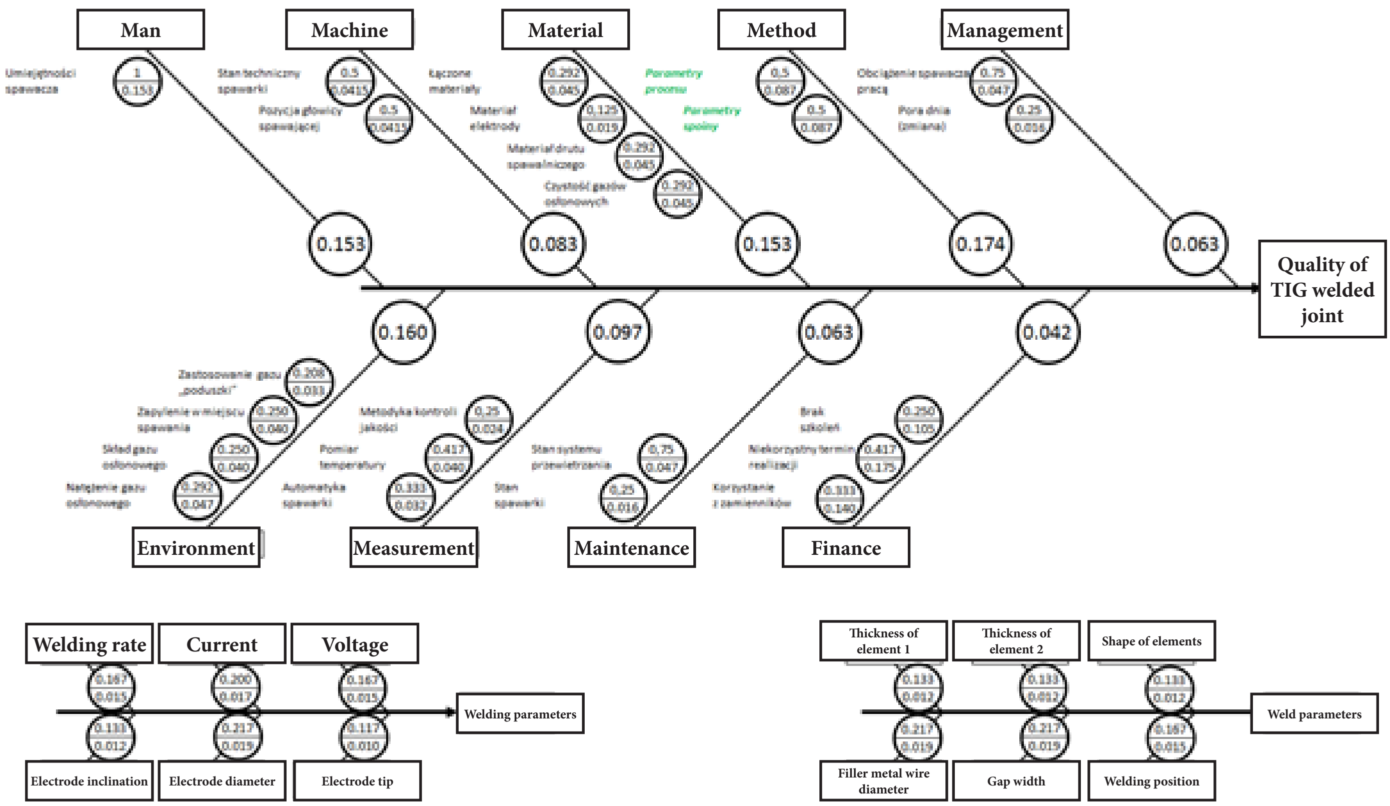

Fig. 4. Weighted Ishikawa diagram for the TIG manual welding process including distinguished elementary reasons

	Man	Machine	Material	Method	Management	Environment	Measurement	Maintenance	Finance	Weight functions	Standardised weight functions
Man	x	0,75	0,5	0,5	0,75	0,5	0,75	0,75	1	5,5	0,153
Machine	0,25	x	0,25	0	0,5	0,25	0,5	0,5	0,75	3	0,083
Material	0,5	0,75	x	0,5	0,75	0,5	0,75	0,75	1	5,5	0,153
Method	0,5	1	0,5	x	1	0,5	0,75	1	1	6,25	0,174
Management	0,25	0,5	0,25	0	x	0,25	0,5	0,5	0,5	2,75	0,076
Environment	0,5	0,75	0,5	0,5	0,75	x	0,75	1	1	5,75	0,160
Measurement	0,25	0,5	0,25	0,25	0,5	0,25	x	0,75	0,75	3,5	0,097
Maintenance	0,25	0,5	0,25	0	0,5	0	0,25	x	0,5	2,25	0,063
Finance	0	0,25	0	0	0,5	0	0,25	0,5	x	1,5	0,042
										31	**1**

Fig. 5. Pair comparison diagram for main groups of reasons

of the narrow estimation of weight function grades. The determination of indicated reasons and their comparison in pairs enabled the more extensive and precise identification, systematisation and hierarchisation of weld quality-related risks present in the TIG manual welding process. The primary reasons affecting the quality of welds include welder's skills (Man group) as well process and weld parameters (Method group), i.e. electrode diameter, welding current, filler metal wire diameter and the threshold gap.

Knowing the reasons and preventing their consequences (within further works and assessment) enables the improvement of the quality of the welding process itself and the quality of welded joints. The above-presented problem analysis, involving the use of the weighted Ishikawa diagram, also presents the potential of the method discussed in the article.

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