



A fast and robust decision support system for in-line quality assessment of resistance seam welds in the steelmaking industry

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ABSTRACT

Assessing the quality of a weld in the steelmaking industry is a complex task. The level of complexity increases when the assessment is based on non-destructive tests. Skilled technicians are often required to make a decision based on automatic assessments of welds. Technicians consider the results of the automatic assessments and use their expert knowledge in order to make a final decision about the quality of the weld. In this paper we propose a decision support system to assess the quality of resistance seam welds of steel strips based on statistical analysis of both the mechanical and electrical variables involved in the welding process to be assessed as well as previously recorded historical data of similar welds. The proposed system is designed following component model based software architecture. The system consists of a set of orthogonal modules: welding variable measurement, welding variable processing and welding quality assessment, communicated by means of dedicated interfaces. The proposed system has been installed in three steel manufacturing lines. With the reduction in the time spent by technicians to make a decision about each weld, the productivity of the manufacturing line has greatly improved. Furthermore, production costs have been reduced since the number of defective welds assessed as non-defective was reduced, and thus the failures in the manufacturing lines due to weld breakages. The experimental results after two years of use in a steel strip galvanizing line are shown.

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1. Introduction

Welding is a process of utmost importance in the metal industry. The quality of a welded joint determines whether the weld is suitable for subsequent manufacturing processes, or if the joint must be re-welded. Weld quality assessment is a complex task due to the great number of variables involved, such as the mechanics of the welding process, the chemical composition of the workpieces to be welded, and oxides and inclusions dragged into the welding zone. When the weld is part of the final product, or even when it is required for subsequent processes, destructive tests in order to inspect the weld are not possible. In these scenarios non-destructive evaluation must be carried out. Several non-destructive techniques for different types of welding processes have been developed in the recent years, such as ultrasonic [1], X-ray [2] and machine vision [3].

In steel strip manufacturing lines where continuous operation is required one of the most widely used welding processes is

resistance seam welding (RSEW), an automated process where two strips are overlapped and the weld is formed progressively in the overlapped area. In these lines the time available for weld inspection is very scarce. The welded strips cannot be stopped more than a few seconds in order not to affect the downstream manufacturing stages. Therefore, in-line non-destructive tests performed while the weld is carried out are required to meet the deadline imposed by the manufacturing process.

RSEW is a welding process classified in the group of electric resistance welding (ERW) which produces coalescence of faying surfaces by means of the heat generated by the resistance of the strips to the welding current. The heat generated by the current causes partial melting of the strips, which are compressed in the area of the weld. Two disc-shaped electrodes, called welding sheaves, are used simultaneously to clamp the strips together and to apply pressure and electric current as they rotate along the overlapped area. After them, another pair of sheaves, called flattening sheaves, apply pressure along the lap joint to finish the weld. RSEW can be seen as a succession of spot welds along the seam weld. In ERW, resistance spot welding (RSPW) is a broadly studied process. Most of the systems to automatically assess the quality of welds in ERW have been developed for RSPW. Several

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techniques have been applied to inspect RSPW processes, such as statistical analysis of the variables involved in the welding process [4], measuring the dynamic resistance of the weld [5], and measuring the electrode displacement during welding [6]. Most of these systems use pattern classification techniques to recognize defects in the welds automatically, such as fuzzy logic [7], neural networks [5,8], support vector machines [9,10], and ant colony optimization [11].

To the best of our knowledge, automatic quality assessment of welds carried out by RSEW is a relatively unexplored field compared with automatic quality assessment of RSPW. In recent years we have developed a number of prototypes to automatically detect defects in RSEW. In [12] we presented an early prototype which detects defects in RSEW processes of steel strips based on fuzzy logic analysis. In [13] we presented a prototype which is able to estimate the reliability of RSEW of steel strips based on an analysis of the heat reached along the seam weld.

In this work we deal with the task of assessing the quality of the RSEW processes of steel strips, providing a decision support system for technicians of the manufacturing line to determine whether the weld fulfills the required specifications. The main issue concerning in-line testing of RSEW processes is the great amount of electric current required by the welding process (between 10 kA and 100 kA). Ultrasound or X-ray welding inspection systems are affected by the electromagnetical noise generated by the welding current, thus they are not useful for in-line weld inspection of RSEW processes. Therefore, these systems must inspect the weld after the welding process is finished, delaying the reception of the assessment by the technicians or other systems of the manufacturing line. Machine vision systems for weld inspection, which are not affected by electromagnetical noise and can be used in-line, only detect defects on the surface of the weld while internal defects are unnoticed [3,14].

This paper presents a technique for in-line quality assessment of electric resistance welds, which is immune to the electromagnetical noise generated during the welding process. In addition, a system based on this technique to work as a decision support tool for in-line quality assessment of resistance seam welds is proposed. The system has been developed and deployed in three steel manufacturing lines: two steel strip galvanizing lines and one tin manufacturing line. The proposed technique detects not only external defects of the weld but also internal defects based on comparing the welding variables of the weld to be assessed with the welding variables gathered from previous processes in which the same materials and the same welding settings were used, that is, with previously recorded historical data.

This paper is organized as follows. Section 2 describes the decision support system for quality assessment of resistance seam welds proposed in this paper. In Section 3, we describe the implementation of the proposed system. In Section 4, the results provided by the system in a steel strip manufacturing line are presented. Finally, some concluding remarks are shown.

2. A decision support system for in-line quality assessment of resistance seam welds

In steelmaking lines where the whole production depends on a welding process, a skilled technician is required to validate each weld. The welding process joins two strips in order to provide an infinite strip which allows the continuous operation of the line. Since the validation task is extremely difficult, the technician can back up his knowledge with a decision support system in order to make a final decision about the weld with confidence. The system was designed for an RSEW process of two galvanizing lines of steel strips and one tin manufacturing line. In these lines, an infinite strip is obtained by successive welding processes between strips in the input section of the lines.

The highest level design of the proposed in-line quality weld assessment system provides a set of orthogonal modules. Each module encapsulates a certain functionality or data, and communicates with other modules of the system through interfaces. These modules can be grouped into three groups: welding variable measurement, welding variable processing and welding quality assessment, shown together with their interfaces in the component diagram in Fig. 1. In the measurement modules the variables involved in the welding process are acquired. These variables represent the mechanical and the electrical characteristics of the welding process. The welding variable processing modules must extract the knowledge of the welding process. This task is carried out by extracting, filtering and assessing the features of the welding variables and comparing them with the behavior of the variables in previous welding processes. The features extracted must be stored in a database to provide historical information about the welding process for the assessment of future welds. Finally, the welding quality assessment module must combine the assessments given to each welding variable. This combination is based on a quality assessment strategy, which will provide a value identifying the level of quality for a weld. Fig. 2 shows the detailed block diagram of the in-line quality assessment system for ERW processes proposed in this paper.

The strategy used in the final welding quality assessment module must take into account high level policies of the manufacturing line, such as the cost of type I errors, false positives (a low-quality weld positively assessed), and type II errors, false negatives (a high-quality weld negatively assessed). The assessment computed for each weld must be provided to the technicians of the manufacturing line through human machine interfaces and to the process computer of the manufacturing line through wired or wireless dedicated interfaces.

Regardless of the technique used, RSEW or RSPW, REW welding machines are governed by different control programs which are defined based on the physical and chemical characteristics of the strips to be welded. Each control program determines the overlapping of the strips in the welding zone, the voltage to be applied, and the required pressure, among other variables. The welding quality assessment system must be informed of the control program for a specific welding process.

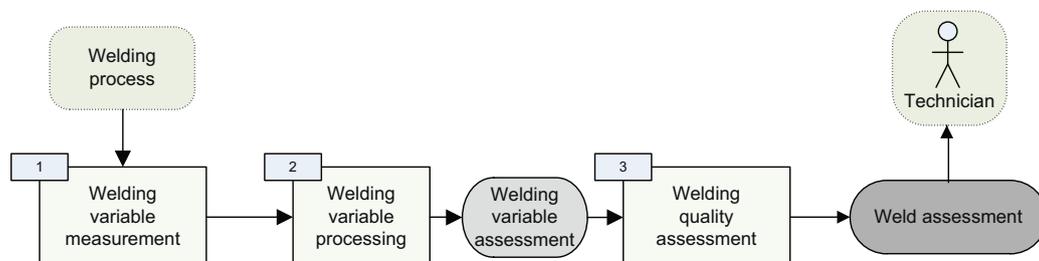


Fig. 1. Highest level of the design of the in-line quality assessment system for electric resistance welds.

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