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Factor Analysis of Lightweight Material Welding Workshop Intelligentization

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Abstract: This study conducts a strategic research on the following three dimensions: final purpose and demand of lightweight material welding, development trends of digitized and intelligentized technology, and flexible construction of the welding workshop. By combining these dimensions with technology development trends of advanced workshop intelligentization and welding process digitization, eight basic factors that lightweight welding workshop intelligentization should satisfy are identified, specifically welding control management real-time transformation, quality control while welding closed-loop transformation, welding analysis datamation, welding technology analysis intelligentization, rapid interchangeable clamping (flexibility), welding line quality inspection instrumentalization, welding production management digitization, and welding foundation database paperless transformation. Furthermore, this paper systematically explains these factors and provides a related conclusion that could be used in reference to the improvement or new establishment of welding workshop intelligentization.

Keywords: Welding technology; Welding workshop; Intelligentization; Lightweight material; Strategic research

1 Introduction

Lightweight materials have extensive applications in automobile, aeronautics, aerospace, and high-speed trains. As an example, the proportions of aluminum alloy on a Boeing 777 aircraft and an Airbus A380 reach 70% and 61%, respectively [1]. The aluminum alloy skin in a honeycomb or foam structure is widely used in high-speed trains. The use of lightweight high performance substitute materials and new formation-type technology have become a significant developing trend of industrial products. When the weight of a car is reduced by 10%, the fuel consumption decreases by 6%–8%, which results to a 4% less emission of exhaust gas [2]. Generally, lightweight materials contain high-strength steel, aluminum alloy, magnesium alloy, carbon-fiber material, engineering plastics, and so on. Among them, lightweight metal and metal alloy materials continue to perform a dominant function, which becomes the focus in the manufacturing industry [3]. The welding of lightweight materials is one of the most crucial processing technologies for lightweight material structure, commonly used in car bodies, aircraft panels, and sandwich plates in high-speed trains [4]. The quality, performance, and manufacturing period of products are directly affected by the welding quality of lightweight materials, and the quality control of the welding technology has stricter requirements, distinguishing it from traditional steel welding [5]. The development of the welding technology for lightweight materials urgently requires a change in the current quality of welding products and dependence on the skill of operators. The achievement of high quality and efficient lightweight material welding products can be supported through the application of the digital intelligent technology and lightweight material welding database. This would result in the

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optimization of welding process parameters and identification of welding defects, elimination of uncontrollable factors (welding cracks, deformation, etc.), and improvement of the welding process.

2 Current status and problems of traditional lightweight material welding workshop

Over a considerable time, although the welding technology of lightweight materials in China can satisfy the basic requirements of products in active demand, several problems persist, such as the backward technology level of production, low quality stability, and large proportion of manual work [6]. In recent years, the automatic welding equipment has been used as a part of the manufacturing process. This has resulted in the semi-mechanization and semi-automatization of the lightweight material welding technology and its remarkable increase in efficiency [7–11]. However, because traditional methods based on manual work and experience continue to be adopted, such as those related to clamping, measuring and other auxiliary segments, selection of automatic welding parameters, and process control, problems on insufficient quality stability and low product efficiency persist. Taking the domestic enterprise of the welding process for the production of lightweight material parts as an example, Fig. 1 presents the main methods of the manufacturing technology in the current welding workshop. As shown in the figure, the present welding process and production status of lightweight materials solely satisfy low-quality or low-yield demand and production requirements.

As described in Fig. 1, there are three main problems in the traditional welding workshop for lightweight materials: ① The quality control of products does not form a closed loop, which largely depends on the skills of technical workers. Moreover, the quality stability of products is uncontrollable. ② Because of the low production efficiency resulting from specific factors, such as the level of parameter optimization, detection means, scheduling mode, clamping methods, and backward methods of defect determination, the demand for rapid and efficient delivery is difficult to satisfy. ③ The process design and feasibility analysis of product manufacture remain dependent on personal knowledge and experience. Additionally, a new product technology frequently requires "trial and error" to obtain a feasible process program, and the flexibility of products by welding manufacturing is insufficient. Concurrently, the rapid replication ability of the production line is weak. Accordingly, the transformation of the traditional lightweight material welding workshop to an intelligent welding workshop mainly focuses on promoting product consistency, increasing manufacturing flexibility, and improving manufacturing efficiency.

3 Analysis of intelligent elements for lightweight material welding workshop

In the automotive and aircraft manufacturing system of advanced industrial nations, automation, sensor, information, robot, and intelligent technologies are widely applied to gradually realize the digital and intelligent manufacturing workshop [12,13], which represents the higher development level of such workshops. Among the typical elements are as follows: ① Rapid response manufacturing has been achieved and product research period has been reduced. These benefit from the digital modeling and simulation of the product and workshop to realize the rapid development of the product or equipment, to the extent that some of the products or parts have been successfully developed simultaneously. ② The process monitoring, detection, and display of operation parameters of the production equipment, including the intelligent analysis, scheduling, and control of the production process are realized by the digitization and networking of the manufacturing site. ③ The workshop intelligence is realized via the precision and intelligence of the equipment. For example, Boeing's digital workshop has applied a large number of automatic auxiliary equipment and digital manufacturing

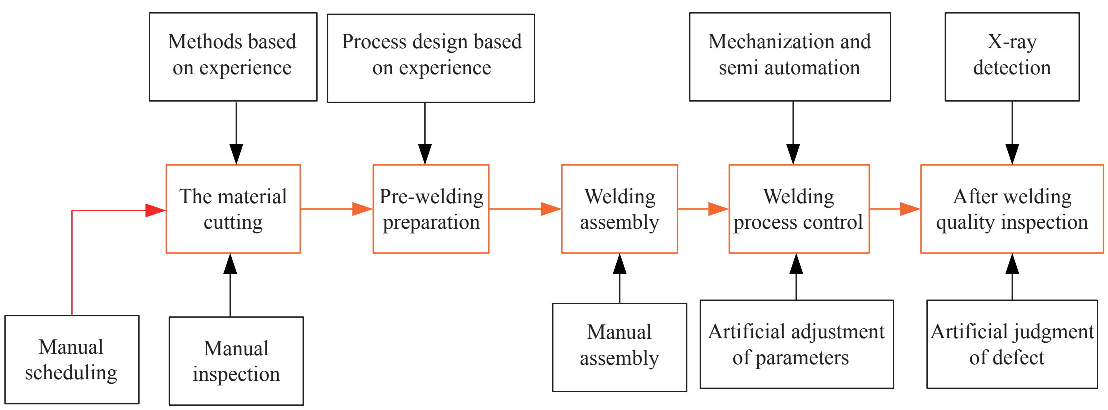

Fig. 1. Current manufacturing technology of welding workshop.

technologies to reduce production time and assembly tooling by 66% and 90%, respectively [14]. Fig. 2 shows the comparison of the typical elements of intelligent workshop abroad and the main problems of the traditional lightweight material welding workshop.

As shown in Fig. 2, in order to achieve the consistency, manufacturing flexibility, and manufacturing efficiency of lightweight material welding products, it is necessary to adopt advanced and mature technical methods, such as simulation modeling, digital networking, and intelligent manufacturing unit, in order to solve problems associated with the dependence on technical personnel, unclosed loop of the on-site manufacturing information, backward detection technique, backward dispatching mode, and lack of online analysis technique. The intelligence of the lightweight material welding workshop should satisfy the dimensions requiring technology development, and dimensions of the target demand and workshop construction.

Based on the development of foreign technologies, including the intelligent welding technology, the intelligent welding workshop item (Fig. 3) is selected in order to analyze the intelligent elements in the welding workshop of lightweight materials. The intelligent welding workshop completed the configuration of the driving and control systems for the welding equipment; defined the welding method, process parameters, and range; established the relevant database; stored and compiled the data of the existing welding process; intercommunicated with the operator via the intelligent terminal installed in the welding equipment and gradually filled it with database to be shared with welding workstations; compiled and optimized the program of welding process parameters according to the original data of the type specifications of the parent material, welding methods, and types and specifications of welding materials; compiled the procedures for automatic correction and compensation based on the shape, size, and seam of joints; scheduled the program for the automatic control of welding quality, alarm program for out of control processes, and program for parameter display and recording, according to the standard for the real time-detection of welding procedure parameters and preset parameters; compiled the program for remote monitoring according to the welding arc and shape parameters of the weld path; scheduled procedures for automatic diagnosis, alarm and repair of the wire feeder, and welding power in the driving and control systems; established data communication between the control systems of the welding equipment and distributed control system (DCS) in order to complete the management, distribution, and collection of the production data of the numerical control program, together with process monitoring and remote diagnosis functions [15].

Based on the dimensions for workshop construction and target demand, the intelligent welding workshop is controlled and deployed by DCS. According to the production task under the

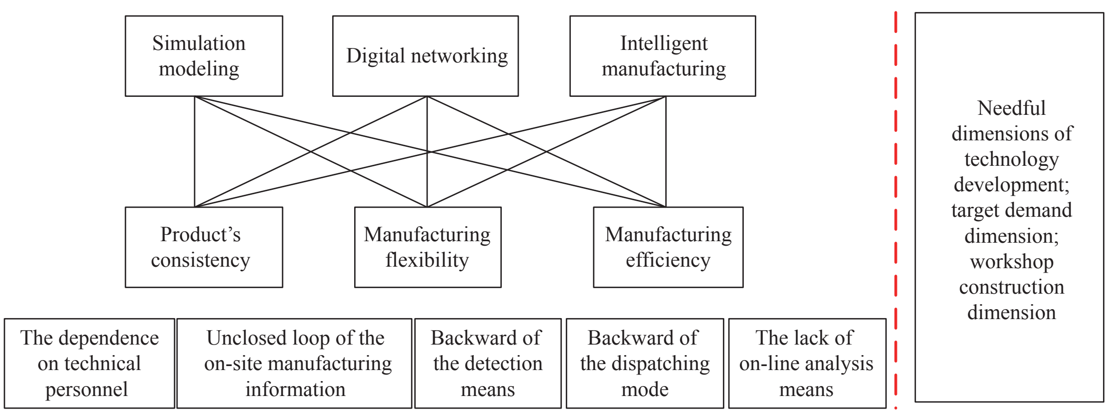

Fig. 2. Intelligent factors for a lightweight material welding workshop.

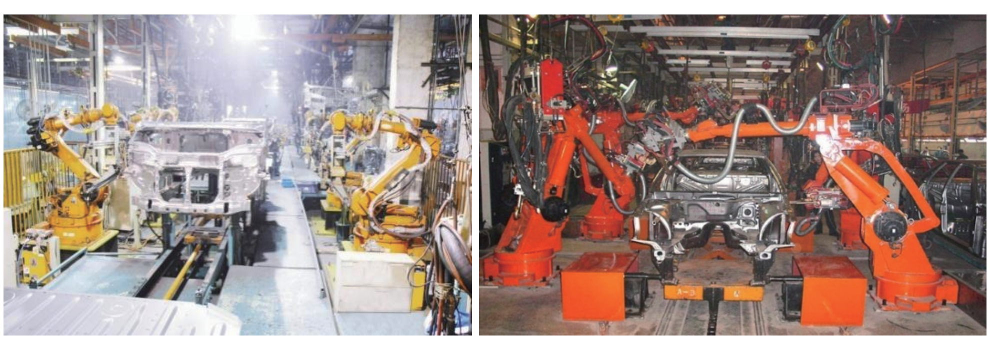

Fig. 3. The intelligent welding workshop.

management layer, the system presets the action program and test data in order to determine the entire manufacturing process. Finally, welding instructions are executed, and processing parameters are acquired in real time for online detection, quality control, welding process monitoring, analysis, and process optimization. From the perspective of welding scheduling and control management, the basic elements of the intelligent construction of the welding workshop are digitalization of the welding production management and real-time control of management. From the perspective of rapid adjustment and flexible switching of the welding equipment, and quality assurance, the fast interchangeable clamping (flexible) and welding quality inspection instrumentalization are basic elements for the intelligent construction of the workshop.

From the development dimension of the welding technology, digital and intelligent welding technologies have caused the integration and simplification of the welding workshop equipment, and the quality of products is accurate and reliable. Foreign manufacturers of Fronius, ESAB, and Lincoln spearheaded the realization of the full digital application of the welding equipment, as well as the precision operation of microprocessors to control the performance and working process of welding, revolving around the welding quality, efficiency, spatter, and so on, to continuously improve the welding control technology. Consequently, the digital intelligent welding is integrated and simplified. Compared with the traditional welding technology, which is dependent on the welding personnel, digital intelligent welding can simultaneously realize metal inert gas/metal active gas (MIG/MAG) robot welding, tungsten inert gas (TIG) welding, and manual arc welding employing a single machine. It responds to the change of the arc length within a considerably small amount time to make the control unprecedented, accurate, and reliable. Furthermore, software upgrade can be applied on different occasions to ensure the consistency of the welding quality and appearance of the weld. With the accurate operation of the microprocessor, a large number of expert systems has been integrated inside the digital intelligent welding system, which can satisfy all types of welding codes and achieve precise arcing. For example, the welding machine of OTC M350L focuses on the improvement of the welding technology under the control of a digital power supply, in order to achieve the same low spatter MAG welding, but with less splashing than similar welding machine can achieve, and improve the surface quality of the workpiece. Moreover, the Transplus synergic 2700/4000/5000 series products of Fronius can employ a variety of welding methods, such as MIG/MAG, TIG, and manual arc welding in one welding machine. It can store approximately 80 welding procedures, perform process management, and control software upgrade through the network [16]. From the requirement dimension of the technical development target, the basic elements of the intelligent welding workshop are closed loop in terms of the welding process quality control, paperless welding database, datamation of the weldability analysis, and intelligentization of the welding process analysis.

4 Basic elements of intellectualization in the welding workshop of lightweight materials

Based on the analyses of the foregoing factors and in view of the development dimension of the digitized intelligent technology, final target and demand dimension of the welding, and dimension of the flexible construction of the welding workshop, it is determined that the intelligence of the lightweight material welding workshop should satisfy eight basic elements, as follows: real-time welding control management, closed-loop quality control in the welding process, datamation of the welding analysis, intelligentization, rapid interchange clamping (flexible), welding quality inspection instrumentalization, welding production management digitalization, and paperless welding database.

4.1 Welding control and management system for lightweight materials

The welding control management system for lightweight materials is a welding process management system based on the information collection of the workshop equipment, industrial field information, and data statistics of workshop network. It realizes the condition of welding operation, real-time data, historical data and warning record storage based on the fault classification of welding equipment and the quality decline of welding products to intelligently analyze and forewarn and diagnose, obtaining preliminary results for operation and management reference welding control and management system for lightweight materials is the main platform for data collection and control in welding workshop.

4.2 Quality control system of lightweight material welding process

The quality control system for the welding process of lightweight materials realizes dynamic closed-loop control of welding process parameters. It is based on high precision online measurement and online detection data instead of artificial detection and adjustment compensation. Consequently, it can dynamically adjust the assembly clamping system, and adjust and optimize the assembly process. The record of welding process parameters (welding seam track, weld gap, and transmission control protocol) is acquired through the application of the laser sensor tracking welding process, welding path adaptive technology, visual sensing weld formation control technology, arc length adaptive control technology, and constant pressure adaptive control technology. The computer adaptively adjusts the welding path and parameters of the robot to achieve adaptive closed-loop control of the welding. The welding quality can be traced by the quality analysis system and intelligent analysis of the fault analysis system. In addition, the adaptive control system for the weld seam can provide the stability and quality control of the welding process by selecting the appropriate light reduction and filtering system to obtain the weld pool image according to the specific welding process for the lightweight material and robust image processing algorithm for the development of the workpiece material. Moreover, the knowledge modeling of the welding process is built through fuzzy identification and rough set theory. The intelligent control strategy for controlling the weld formation and quality is designed according to the information of the dynamic geometry size, gap between the weld, and weld penetration. The quality control system of the welding process is the basic premise for realizing the closed-loop information for lightweight materials, consistency of welding quality, and intellectualization of welding.

4.3 Expert system for the weldability analysis of lightweight materials

The expert system for the weldability analysis is a database, which takes the database of the lightweight material test, selection of welding methods, and digital results of the sensitivity analysis for welding cracks, as objects of study. The lightweight material test database can organize and classify the welding test data of lightweight materials, such as aluminum alloy and thin-walled steel, and digitize and manage data in the form of a database. Technicians can directly access the welding test data of related lightweight materials through the database. The welding method selection can provide the basic required information as input, supplemented by comprehensive analysis in order to determine the appropriate welding method according to specific factors (quality, efficiency, cost, etc.) in order to achieve the best results. The sensitivity analysis of welding cracks is based on the correlation between welding process and the sensitivity of welding process. The method of fuzzy reasoning is used to analyze the welding process and provide the prediction of the crack size and position. The expert system for welding analysis is an important basis for improving manufacturing efficiency and ensuring product consistency.

4.4 Expert system for welding process analysis of lightweight materials

The expert system for welding process is a database which is established based on the knowledge of the lightweight material welding process and inference on the welding process. On the one hand, the system can realize automatic and intelligent design of the lightweight material welding process, including common welding methods of lightweight materials, various grades of materials, selection of welding materials, welding joint design, and available parameters of the welding process [17]. On the other hand, it can be compared with the existing technical knowledge, such as the welding method, welding material, material brand, and welding joint in order to enrich the knowledge database of the welding process and perfect the welding process reasoning mechanism [18]. The expert system for process analysis is the precondition to realize automatic welding automation and improve welding efficiency.

4.5 Rapid interlocking and clamping system of lightweight material welding

The rapid exchange clamping system of lightweight material welding is based on the mature robot and auxiliary automation equipment, which solve problems associated with the traditional welding clamp, such as the single species, excessive welding tooling, complexion of the storage management, and slow switch response time. It adopts uniform design specifications and standards, consequently, improving interchangeability, realizing multi-purpose use, making possible the design of modular and modular flexible welding tooling, and realizing mechanical quick positioning and electric quick switch. The fast switching and clamping system is an important factor to achieve welding automation, improve welding efficiency, and enhance welding manufacturing flexibility.

4.6 Welding quality inspection system for lightweight materials

The quality inspection system for lightweight material welds is different from the current technique that utilizes film imaging, size of defects, and the artificial judgment of category. The quality inspection system applies the X-ray [19], integrated ultrasonic-phased array, and other digital real-time imaging systems [20], or the laser sensing system to achieve high precision automatic detection and judgment of welding defects to trace the quality of the welding process [21]. Weld quality inspection is an effective control method for welding quality, interspersing in all aspects of welding, and serves as a permission for a welding procedure. The advanced quality, real-time detection and detection efficiency for lightweight material weld quality testing tools perform a crucial function in the entire welding manufacturing cycle.

4.7 Management system of lightweight material welding production

The welding production management of lightweight materials is based on the technology of electronic kanban, sensing, simulation, and so on. It integrates the systems of product data management, enterprise resource planning, manufacturing execution system, computer-aided process planning, and computer-aided manufacturing through the engineering database and its application interface. This integration makes it possible to realize the mutual contact and interaction with the equipment, supporting the speed and accuracy of the theory in order to realize quick response manufacturing capability and meticulous management. The lightweight material welding production management system is the core platform for welding workshop information, equipment, personnel scheduling, and control.

4.8 Basic database of lightweight material welding

The basic database of welding is one that is built according to the welding parent material, material, procedure, standard, and defect. The database of the welding parent material mainly contains chemical composition, thermal physical property, and mechanical properties of this parent material. Technicians can directly access related data on the welded material in lieu of reading the standards from the manual on paper. The database of the welding material primarily stores related data and production information pertaining to this material. The difficulty experienced by technicians in the selection of the appropriate welding material can be substantially reduced by directly accessing data pertaining to related welding materials and contact information of manufacturers. The database of the welding process includes not only similar welding technologies, but also the basic knowledge of the welding process design. Technicians can directly access the database and obtain mature process data or the technology number as reference. The welding standard database is convenient for technicians to make queries on related standard systems. The database stores all types of welding defects in the welding production. This makes it convenient for users to make queries and quick analyses. The basic database is an important guarantee for achieving product consistency.

5 Conclusions

This paper describes the technical means and existing problems of the traditional welding workshop, along with the elements of foreign automobile and aircraft advanced manufacturing workshops. It summarizes the intelligent function of an advanced intelligent welding workshop project in the automotive field in terms of three dimensions—the final target and demand of welding, development of the digital intelligent technology, and construction of the welding workshop—as basic dimensions of intelligent elements of the welding workshop. In addition, eight basic elements of the welding workshop are obtained in combination with the development trend of the digital intelligent technology of the welding process. Specifically, these elements are welding control and management system, quality control system of the welding process, expert system for the weldability analysis, expert system for the welding process analysis, rapid interlocking and clamping system of the lightweight material welding, welding quality inspection system, management system of the welding production, and base database system of welding, all of which provide reference for the transformation and construction of a digital intelligent welding workshop in the welding industry and enterprise.

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