Impact of Process Modelling on Current Direction of Welding Research and Future Targets

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ABSTRACT

Abstract: The present paper gives a description of process modelling and its impact on current direction of welding research and future targets. It analyses the research work carried out in the filed of process modelling and presents quantitative analysis. The present work classifies and subsequently quantifies the welding research on the basis of approaches including modelling and simulation, product development, cause-effect analysis and sensor and control. The analysis indicates that modelling based research is primarily reported for existing technologies and existing materials. Research in new technologies using modelling is still is in developing stages and new materials based research is primarily carried out with cause-effect based analysis. The paper also mentions the future targets in welding research and indicates the role of process modelling in achieving the targets.

Keywords: Process modelling, welding research, future targets

INTRODUCTION

Discovery of a novel scientific idea is a seldom happening. Serendipity along with life-long involvement of many researchers results in origination of a new concept. Still the process of understanding and deriving applications continues. This leads to continuation of the procedure termed as research or rather 're-search'. The wheel was invented once but research on wheel still continues. Need combined with zeal to make things better must be the main reason behind the research. Entities, either natural or manufactured, follow certain rules. A combination of many entities makes a system. Thus, research can be related with understanding of such systems even when the behaviors of the entities are well understood. Many a times, information regarding a system is well known and dynamics of the system can be laid on a piece-of-paper. Furthermore, a functional relationship between behavioral pattern of the system and its governing factors can be arrived at. In pre-computer age, research was mainly based upon cause-effect analysis. The research was supported by experimentation on physical model (prototype) along with fundamental mathematical concepts. However, mathematical understanding of any phenomenon was constrained by limited computational capacities. Thus, analytical or empirical expressions were developed with certain simplifications and assumptions.

With the development of high-speed computational capacities around 1980, it became possible to represent any system in a better manner. The cause-effect analysis combined with computational capabilities significantly governed the direction of research. Physical models started to be replaced by virtual models developed with the help of computer codes. As a result, term 'model' became synonymous with mathematical or computational scheme which was a virtual substitute for an actual system. This development enhanced the understanding of systems, as the model could be simulated in order to understand the system. At the same time, cost involved in experimentation could also be saved. Thus, development of a model became an important tool for research. Moreover, the modelling also penetrated in industrial systems, not only to understand the systems but also to develop real time control. The following section gives a brief description of process modelling which is followed by impact of process modelling on manufacturing. The next section gives present status of welding research followed by targets in present of welding research and role of process modelling in the same. The article ends with conclusion drawn on the basis of the analysis in the sections mentioned above.

IMPACT OF PROCESS MODELLING

At present, impact of modelling can be felt in all streams of research including basic sciences, engineering, and management as well as in economic and social studies. In case of engineering processes, the role of modelling becomes more significant as it becomes instrumental in productivity enhancement. The role of process modelling in productivity enhancement can be depicted with help of a chart, as shown in Fig 1. Manufacturing, as technology, process or production system, has also benefited by the exercise of modelling. The last 10 years have observed a tremendous growth in the area of modelling related research. This fact can be examined in the Fig. 2. This figure shows year wise number of research articles dealing with modelling in the field of manufacturing, published in various journals and conference proceedings. The data for this year wise distribution has been collected through SCOUPS [4]. It is to be noted that this distribution is representative rather than actual as it may not cover all of the published as well as unpublished works. Nevertheless, the collection is so large that it can be used to understand the direction of research in the modelling based studies in the manufacturing field. It can be easily seen that prior to 1980, the modelling based studies were almost non-existent. In 1980s, this field started to grow and it is still continuously growing. Further deliberation on the above stated publications reveals that a major portion within manufacturing related studies is covered by investigations into manufacturing technologies like machining, casting, fabrication etc. An overview of modelling based investigations in manufacturing technologies indicates five major types, including:

a) Predictive modelling
b) Optimization
c) Numerical modelling of physical phenomenon
d) Online control
e) Offline simulation

Various tools are being used to carry out the above stated five types of modelling exercises. These tools include conventional tool like regression analysis, numerical modelling tools like finite element method (FEM) and computational intelligence based tools like artificial neural network (ANN), fuzzy logic, genetic algorithm, simulated annealing etc.

Among the various manufacturing technologies, welding possesses an important and unique standing. The term 'Welding' designates a wide range of joining techniques that include fusion welding, solid state welding, weld-bonding, diffusion welding, brazing and soldering. In addition, with some smaller modifications, the welding process can also be used for cutting process. Thus, it finds wide application and offers cost effective, reliable and safe operation. The role of welding and joining in the repair and life extension of manufactured products is even more critical since these processes are frequently used to repair structures and components that were not originally welded [5]. Impact of modelling is also being observed in the welding research. Existing processes as well as newly developed process are being investigated in the frame-work of modelling. The following section examines the present state of welding research in quantitative and qualitative manner.

PRESENT STATE OF WELDING RESEARCH

During last century, welding has evolved as a science. Due to its practical applicability, its connection with industry is as strong as always. Thus, research and industrial applicability of welding always go side-by-side. Present state of welding is mainly governed by two requirements: high production rate and consistent weld quality. In order to attain these requirements, research is being conducted on existing technologies and materials as well as on new material and new technologies. Demand for welding research in new materials like composites, arises from the requirements of product specifications which new materials can fulfill. However, irrespective of the material or technology, either existing or new, fundamental requirements of high productivity and quality are always present. Industrial applicability of the process can be justified by these two twin issues. These two requirements are interrelated in the sense that increment in welding speed in order to attain higher production rate is restricted by the nonconformities attained at higher speed. This interrelation has made a significant impact on the direction of welding research. In order to take stock of the situation of welding research, an analysis has been made regarding the articles published in the various journal and conference proceedings in the year 2006 on the basis of data available with SCOPUS [4]. More than 1800 articles were listed for the year 2006. From analysis point of view, these articles have been classified in four categories as following:

a) Existing technologies applied to existing materials

b) Existing technologies applied to new materials

c) New technologies applied to existing materials

d) New technologies applied to new materials

PROCESS MODELLING

'Process modelling', is defined as follows [1]

"Process modelling is the concise description of the total variation in one quantity, y, by partitioning it into a deterministic component given by a mathematical function of one or more quantities, x_1, x_2, x_3........ , and a random component that follows a particular probability distribution"

The interrelation developed by the above stated process is termed as model that identifies the behavioral pattern of the process under consideration. A concise description of the model given in Engineering Statistics Handbook, National Institute of Standards and Technology [1], which is as following:

The 'model' consists of three parts,

a) The response variable, also termed as dependent variable or measured variable, y

b) The mathematical function, f

c) The random errors, ε

Thus, in general format the model is designated as

$$y = f(\vec{x} : \vec{\beta}) + \varepsilon \qquad (1)$$

The mathematical function f consists of two parts. These parts are the predictor variables, x_1, x_2, x_3......., and the parameters, β0, β_1, β_2, ... The parameters and predictor variables are combined in different forms to give the function used to describe the deterministic variation in the response variable. In its correct usage, the term "model" refers to the Eq. (1) and includes the underlying assumptions made about the probability distribution used to describe the variation of the random errors. The research fraternity uses different tools to model a process. These techniques can be listed as follows:

a) Analytical modelling

b) Numerical modelling

c) Statistical modelling

d) Semi-statistical modelling

e) Computational intelligence based modelling

f) Hybrid modelling

The first two modelling techniques stated above are directly related to the physics of the process. In the first technique, empirical relations between independent and dependent process parameters are developed. These studies generally do not fully capture the process phenomena due to limitation posed by the assumptions made during development of the empirical relations. The numerical modelling overcomes many of the limitations of the analytical studies as it approximates the system behavior and solves it by means of computation supported by high-speed computers. The numerical models frequently need 'fine tuning' of one or more 'empirical parameters' to achieve accurate compliance with actual process [2]. Apart from that, these studies are too complicated to be applied frequently at industrial level.

The other modelling techniques, namely, statistical modelling, semi-statistical modelling, computational intelligence based modelling and hybrid techniques are more related with practical implementation at industrial level. The statistical modelling develops relation between independent and dependent process parameters with help of regression analysis. It maps the relationship with the help of some known results and develops an equation which can be used to predict the process outcomes. These types of equations are very useful for practical uses. However, these types of equations are developed with a presumed form like curvilinear, linear, quadratic etc. In the later stage, the adequacy or fit is checked with statistical tests. If the process possesses some other type of trend or high degree of non-linearity then statistical modelling sometimes fails to model the behavior of the process. Thus, some of the investigators have chosen a middle course in which the process is modeled using derived variable based upon physics of the system.

In the recent times, computational intelligence based modelling has become quite popular among the investigators. Computational intelligence refers to intelligence artificially realized through computation [3]. Artificial Intelligence emerged as a computer science discipline in the mid 1950s. Since then, it has produced a number of powerful tools, some of which are used in engineering to solve difficult problems normally requiring human intelligence. The past two decades have witnessed the resurgence of studies in neural network, fuzzy logic and genetic algorithm which in combine are called as computational intelligence [3]. These types of modelling techniques are frequently used in predictive modelling as well as in optimization of the process. The nonlinearity, as mentioned in the previous paragraph, can be better modeled with computational intelligence based modelling. Furthermore, different techniques are also used in combination, thus, benefits of different techniques can be combined. This clubbing is termed as hybrid modelling. Combination of regression with neural, fuzzy with neural, genetic algorithm with neural and fuzzy are some of the examples of hybrid modelling. The above stated techniques have an impact on the direction of the research in manufacturing processes. The subsequent section analysis this impact.

Here, existing technologies refers to those which are successfully running in the industries whereas new technologies are those which are either at laboratory stage or comparatively new and not so commonly available. Conventional welding techniques like submerged arc welding (SAW), metal inert gas (MIG), tungsten inert gas (TIG), resistance welding etc as well as non-conventional welding process like LASER beam welding (LBM), electron beam welding (EBM) etc. have been considered in the former whereas friction stir welding, hybrid welding etc. have been considered in the later. On the other hand, new materials cover alloy and composites which have not been so often reported in the past. Moreover, articles classified in above categories have been further classified in four different groups, namely,

a) Modelling and simulation

b) Application of welding technology for product development

c) Cause-effect analysis

d) Sensor and control

The first group, i.e., modelling and simulation deals with understanding of different physical phenomena occurring during and after welding. This group covers melting, solidification; thermal responses along with process outcomes like weld bead geometry, residual stress, distortion etc. The second group covers examination of feasibility of welding process for product development intended for various applications. In the third group, i.e., cause-effect analysis, experiments are carried out and the results of experiments are analyzed on the basis of the physics of the process. In this group characterization of different features like mechanical properties, microstructure, corrosion etc. are investigated. The last group is related with automation where the mechanism of process control and monitoring are studied. A quantitative analysis of above stated categories and groups has been sown in Fig. 3. The quantitative analysis offers very interesting information. A majority of research work, around 67% has been reported for existing materials and existing technologies whereas the new material and technology combination has been least (say around 5%) reported. The other two categories come in between. Furthermore, this analysis gives a clear picture of the direction of welding research. The major findings are as follows:

a) Cause-effect analysis is the mostly applied tool for welding research irrespective of type of material and technology.

b) In line with overall manufacturing scenario, modelling and simulation based studies in welding also being reported. However, these studies are primarily related with existing technologies and existing materials.

c) Sensor and controls based studies have a fair representation in the category of existing technologies and existing materials; however, this group is almost non-existing in other categories.

d) Modelling and simulation along with application based studies are in developing stage in reference to new technologies.

e) New materials based research is primarily carried out with cause-effect based analysis.

Thus, the direction of welding research is driven by industrial requirement of making the existing process better as well as it is self-driven to search new avenues. The direction of welding research has been continuously observed, evaluated and further deliberated by different organizations working in the field of welding. In turn, future targets for welding related activities have been assigned. These targets are discussed in the following section.

TARGETS FOR WELDING RELATED ACTIVITIES

Many organizations around the world are devoted to welding related research and development. Among them, American Welding Society (AWS) is one of the leading organizations. In year 2000, AWS documented the forthcoming targets for welding related activities in form of a report titled 'Vision for Welding Industries' [5]. This report gives a detailed discussion regarding status of welding industries, key driver to welding future, targets and the challenges welding industry is going to face, up to the second decade of 21st century. In particular, the section 5 of this report discusses strategic targets for 2020. The targets given in this report have been classified in following sections:

a) Cost and productivity

b) Technologies and processes

c) Quality standards

d) Material performance

e) Markets and applications

f) Education and training

g) Energy, environment, health and safety

Each of the above stated targets have been described in details with objectives and related tasks. The first two targets which are important from point of view of research in welding processes are described in the Table 1. It is evident from the above table that in order to attain the objectives of the targets, modelling and simulation have been repeatedly emphasized. It is clear that the investigators engaged in welding research are required to emphasize on application of modelling and simulation exercise to enhance cost effectiveness of existing welding process. Apart from that, new technologies and processes with the use of simulation technology to model entire manufacturing sequence are also to be developed so that the welding time in manufacturing can be reduced.

Importance of modelling in the welding can also be found in other documents like, 'Trends in key joining technologies for the twenty-first century' [6]. This document categorically says, "What will really make welding a success, however, is better process modelling using (coupled) models which capture the electrical, mechanical, thermal, and metallurgical (or material) phenomena. Whether the physics of processes is modeled precisely, or models which do not depend on understanding the physics like neutral networks and fuzzy logic are used, process control for increased automation will be the key to the future of welding." Thus, it is quite apparent from the above discussion that use of modelling in existing and new technologies along with development of new technologies is the key for more successful welding operations.

CONCLUSIONS

On the basis of the above discussion the following conclusions can be arrived upon

a) A rapid growth in research in manufacturing area using process modelling is observed and modelling has established as an indivisible ingredient of research.

b) Investigators in welding area are mainly using modelling tool for research in existing material and process.

c) Research in new technologies using modelling is still is in developing stages and new materials based research is primarily carried out with cause-effect based analysis.

d) The future targets in welding research could be achieved with help of process modelling in various forms including predictive modeling, simulation of entire welding process model and sequence model and evaluation of alternative technology with improved simulation models.

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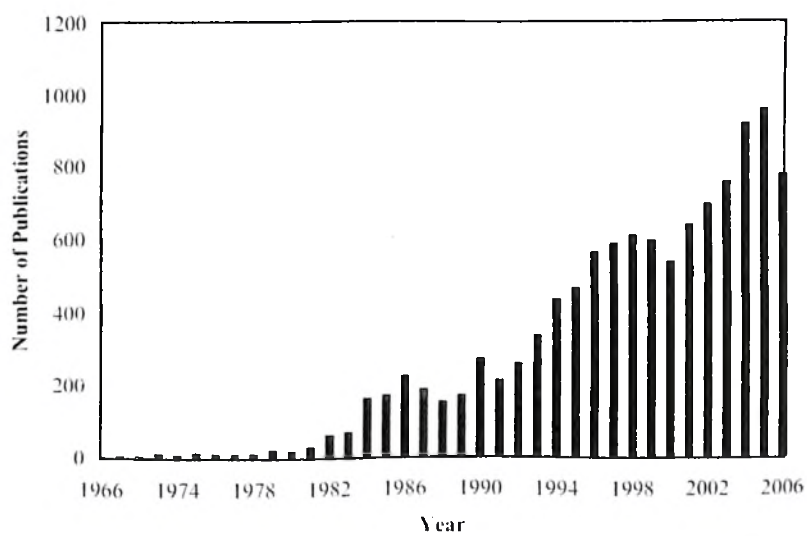


Fig. 2 Research publications related with modelling based studies in manufacturing

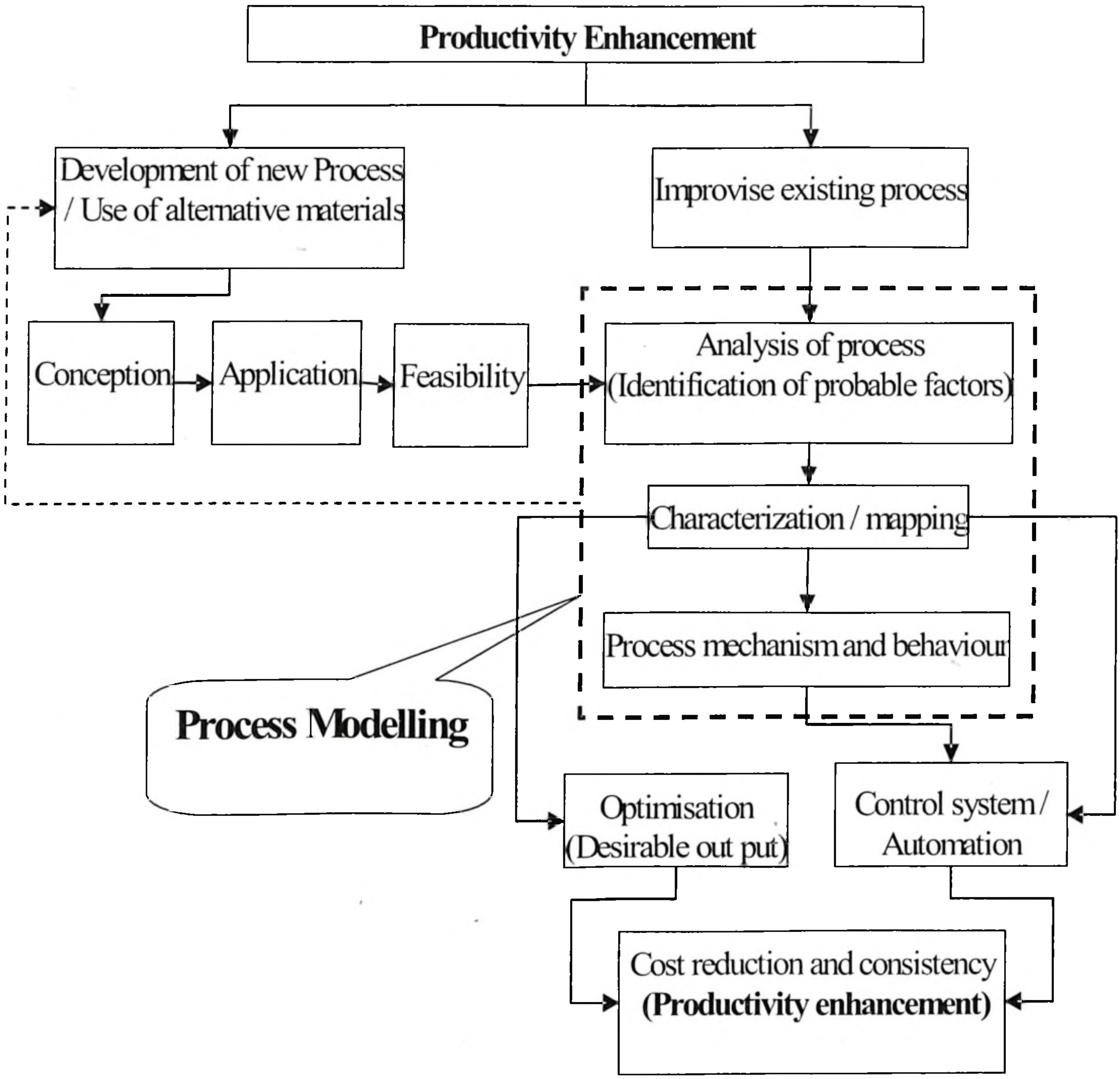
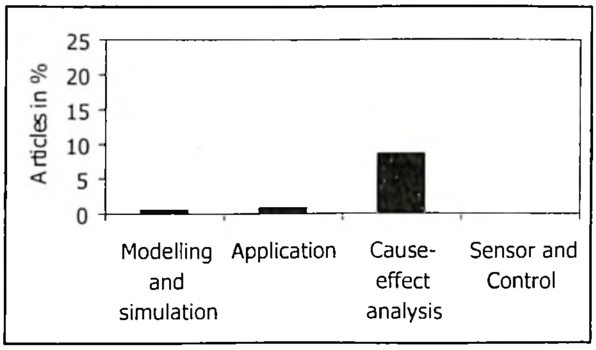


Fig. 1 Productivity enhancements through process modelling


Articles in %
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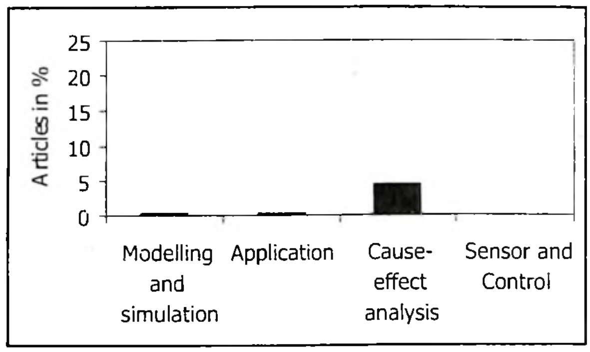
Modelling and simulation
Application
Cause-effect analysis
Sensor and Control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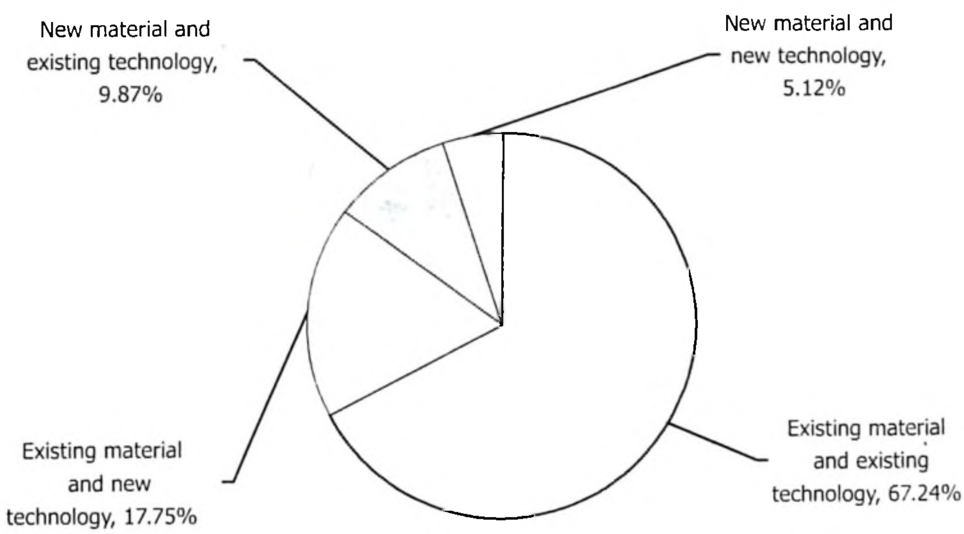
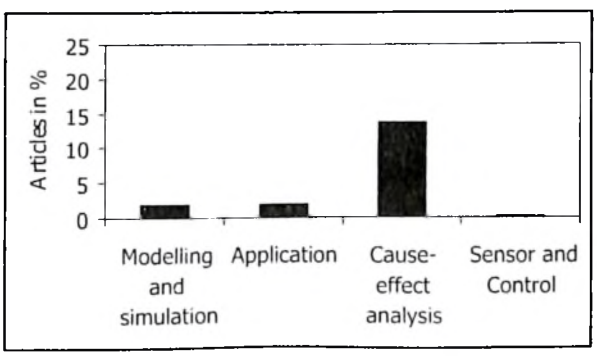

New material and existing technology, 9.87%
New material and new technology, 5.12%
Existing material and new technology, 17.75%
Existing material and existing technology, 67.24%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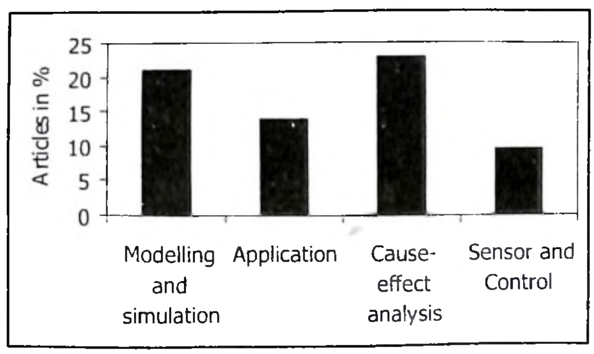
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Modelling and simulation
Application
Cause-effect analysis
Sensor and Control

Targets	Objectives	Related Tasks
COST AND PRODUCTIVITY	Achieve cost-effective welding operations	Conduct "up-front" design and development (modeling, process/materials databases) to achieve a greater market share; strive to compress the time and associated costs for this work by a factor of 10 in the future
	Increase productivity and throughput by 100%	Improve weld quality, reduce welding time during manufacturing, use automation to decrease labor costs, use simulation to model the welding and the manufacturing process
TECHNOLOGIES AND PROCESSES	Enhance use of welding in manufacturing operations	Develop new technologies and processes, use simulation technology to model entire manufacturing sequence (will be important to industry's progress in 21st century)
	Conduct virtual qualification of weld designs	Evaluate welds and alternative joining techniques at design phase, improve simulation technologies