

# Developmental Direction of Welding Materials and Processes to Improve the Effectiveness

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**Abstract:** -- Demands for improved productivity, efficiency, and quality pose challenges to the welding industry. As materials become ever more sophisticated in their chemical composition to provide ever-better functionally specific properties, a more complete and precise understanding of how such materials can be joined for optimal effectiveness and efficiency will become essential. Traditional options for welding will surely evolve, sometimes to provide unimagined capabilities. In addition, totally new methods will almost certainly emerge as evolution of materials gives way to revolution to meet unimagined new designs and design demands.

The paper considers process systematization and corresponding advances of constituent technologies, discusses some of the role and future direction of welding technology, welding materials, productivity and efficiency, education and safety having an impact on future growth in welding technology. Analysis of drivers and the key needs of some manufacturing industries have been researched, giving general trends and strong indications as to expected trends in technology that will be seen in the future. It also provides a good foundation for future research and creates awareness of the developmental direction of welding processes and materials in manufacturing industries.

**Keywords-** welding technology, welding materials, productivity and efficiency

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## I. INTRODUCTION

Metal industries use a variety of methods to join different components and the joining methods can be either permanent or temporary depending on the type and design of the product. The latter methods use parts like bolts, screws, and rivets, whereas permanent joining usually involves welding. Welding is one of the most common joining processes in the metal industry, applied in facilities from job shop outfits to highly-automated computer-controlled factories. The involvement of interdependent factors in the process, such as human resources, market conditions and welding machinery, which varies with the type of metals to be welded and the needs of the customer, demand the use of advanced and comprehensive system design and inspection. Designers and manufacturing engineers need to know the full potential of all available welding and joining processes so they can make the best selection of potential manufacturing methods. Scientific knowledge, engineering, and training must be more closely integrated into the welding process if it is to compete with other technologies and fulfill its potential. Another important determinant of the future of welding is the drive to improve efficiency and productivity. For manufactured products to be able to compete, they must

be made faster, cheaper, and better than those of competitors.

Continuing growth in welding equipment purchases shows that worldwide utilization of welding is still increasing and its use is expected to grow further due to its economic advantages. For the foreseeable future, intelligently designed weldments will always be less expensive for similar applications than will products made by other manufacturing methods. The last couple of decades have seen the significant development in the fields of laser welding, hybrid welding (especially laser-MIG/MAG-hybrid), brazing, FSW, multi-thread techniques, powder plasma, narrow gap techniques, TOPTIG and cold-arc technology [1].

The future growth of welding depends largely on the adoption of modern welding processes and on developments in the materials used. Such materials and alloys include high-strength, low-alloy steels and new high-alloy, high-temperature steels. Thus, new technological strategies are needed, in order to develop welding technology concurrently with the development of new materials [2,3]. Extensive research will also be needed to develop new filler metals and to improve the purity of certain products associated with welding. Improved filler metals with higher deposition rates and

the increased use of computer-controlled welding equipment and processes, which reduce overall labor costs, are the main drivers behind the increasing productivity of welding, and why welding will continue to dominate the materials-joining industry.

Replacement technologies such as polymer bonding, adhesive bonding, and abrasion are being developed and only if welding technology companies continue to promote technological development will they be able to withstand increased competition. The progress in engineering, construction engineering, shipbuilding, petrochemical and oil processing companies and other branches, the higher cost of welder's labor and social problems need new solutions [4].

This paper discusses different aspects of the welding industry, considering opportunities to improve productivity and allow welding to be an engine of growth. Approaches to mitigating the effects of the downturn and safeguarding the future of welding are considered and explained. The paper describes new welding materials that permit such improvement and outlines problems that need to be solved to achieve further progress in welding process.

## **II. WELDING PROCESSES**

Factors such as the use environment, design and assembly method of the structure influence a wide variety of properties of structural materials. Hence, the performance of a structure is often determined by the properties of welded joints rather than those of main materials [5]. There are a lot of different categories of welding processes. The most common welding processes have been considered in this study.

### **2.1. Arc welding processes**

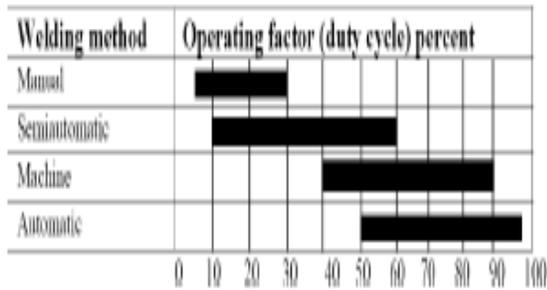
Arc welding, in particular, has been very widely used because of its low cost, convenience, and extremely wide applicability. As a consequence, the arc process has progressed remarkably in the past 30 years as a result of technological innovation aimed at increases in productivity, stabilization of weld quality and labor saving. Recently, these three aims have been linked in the form of advanced automatic welding. It is to be expected that automation will increase steadily, driven as much by a shortage of skilled labor as by new technologies. The most

Successful automation technologies will be simple and inexpensive rather than the high-technology, high-cost approaches which are popular among welding researchers.

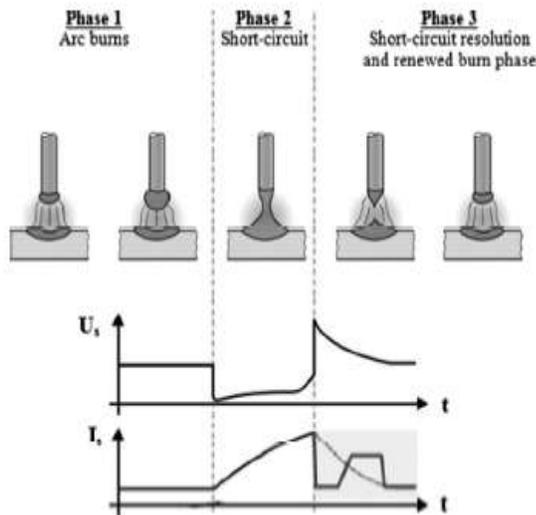
Arc welding occupies the most important position in the group of fusion welding processes, and due to its flexibility and cost effectiveness, it is an indispensable technology for the construction of steel-framed buildings, ship building, motor vehicle manufacture, power plants and other industries. The quality of the weldments produced is particularly dependent on the welding materials utilized and improvement in performance is required. Arc welding will occupy the most important position in the group of fusion welding processes.

Developments in welding power sources have focused on regularizing metal transfer phenomena and increasing the metal deposition rate and penetration depth by control of the current and its waveform. The focus of developments in control technology has changed with increased automatization in welding. The development of various sensors for tracking the welding line and adaptive control of welding conditions in response to groove shape, work shape, and welding position have become development targets. Many combinations of sensors and other devices are evolving to become systematized to include the entire welding equipment and its performance control. This trend has been clearly seen over the last ten years, mainly in the shipbuilding industry.

The selection of the best welding process for a given application depends on the requirements of the job and the extent to which the process provides economic advantages. To a degree, the processes an enterprise chooses determine the type of products that can be produced competitively. The optimum process is that which fabricates weldments at the lowest cost while producing acceptable quality at high deposition rate and with high operator factors. When large quantities of weld metal are required, the operator factor normally increases with increasing mechanization, as shown in Fig. 1 [6].



**Fig. 1. Effect of mechanisation on operator factor, replotted from [6].**



**Fig. 2. Principle of cold arc technology, replotted from [1].**

### 2.1.1. Gasmetal arc welding (GMAW)

GMAW is utilized as a semi-mechanized, fully mechanised or automatic process. Due to the modulation of the electric current, the process can be adapted to the respective special requirements resulting from the material to be processed, the welding position and the component. Developments with regard to controlled energy input as a cold arc or as cold metal transfer (CMT) have attracted attention in recent times [1]. Metal transfer of short arc welding processes is controlled by reducing the current during the short circuit phase (Fig. 2) or by pulling back the wire during or just after metal transfer. These control methods permit very low pattern welding and also the welding of materials which can only withstand a low heat supply or low energy supply

such as highest-strength or surface coated steels. It is to be expected that GMAW will continue to evolve to allow better arc control, better bead contour control, better deposition control (i.e. out-of-position welding and thermal management), and higher productivity (through faster deposition and fewer defects). Utilization of GMAW will also accelerate since, as a continuous wire process with high filler metal utilization, it is an alternative for shielded metal arc welding, gas welding, brazing, and resistance welding.

### 2.1.2. Submerged arc welding (SAW)

The submerged arc welding process, in which the weld and arc zone are submerged by a layer of flux, is the most efficient fusion welding process in plate and structural work such as shipbuilding, bridge building, and pressure vessel fabrication, assuming the work pieces can be properly positioned and the equipment accurately guided. However, when welds must be made out of position or when several short welds are required on many pieces involving frequent moves of the welder or the work piece, a flexible process such as shielded metal arc welding, gas metal arc welding, or flux cored arc welding should be considered. The optimum process is selected based on a compromise between welding speed (deposition rate), versatility, and portability.

### 2.1.3. Gas tungsten arc welding (GTAW)

GTAW is a process that uses a non consumable electrode to heat the work piece to be welded. It is to be expected that GTAW will grow at a rate matching growth in the total welding market. The main reasons for this development are: i) it is adaptable to automation; ii) it is used on high quality work; and iii) it is suitable for welding newer thin specialty metals. However, the technique is unlikely to become a large segment of the total welding. Flux-assisted gas tungsten arc welding is being explored to allow reactive metals (like Ti) to be welded or repaired in the field; building on developments already achieved. Variations of the plasma arc welding process also may provide new capabilities for arc welding advanced materials.

### 2.1.4. Flux cored arc welding (FCAW)

FCAW is a process that uses an arc between a continuous filler metal electrode and the weld pool. Shielding gas from flux contained within the tubular is used in the process. Utilization of the FCAW process started from a lower base and has been gaining modestly. This trend will likely continue; however, lower filler

metal utilization and higher filler metal costs will keep it from growing as fast as gas metal arc welding. In ship and bridge building, metal FCW is habitually used for fillet welding of painted steel plate and slag FCW for all-position welding. For bridges, where principal beams are few and these beams structural members are large in size and thick, the sheet size and the length of the welding leg have also grown; FCW welding is used for the fillet. This welding has come into use not only for 490 N/mm<sup>2</sup> grade steel and 590 N/mm<sup>2</sup> grade steel but also for weather-resistant steel. FCW, with which upward welding is possible at high currents, is used when the gap is large.

### **2.2. Beam welding technology**

In the past ten years, laser and electron beam welding processes have seen enormous development and have been introduced into many fields of manufacturing. Both processes are particularly suitable for fully mechanized or automated utilization and thus likely to be used more in the future. Electron beam welding, as the older of the two, has been applied increasingly and has been able to bring its advantages to bear. These advantages are an extremely high power density and thus a low heat input even in the case of the thickest welds of up to 250 mm and above. The availability of large vacuum chambers, up to 630 m<sup>3</sup>, permits the welding even of large-volume machine components. The possibility of splitting the beam allows the execution of several welds on one component at the same time. Laser-beam material processing will in all likelihood evolve rapidly to take advantage of the lasers exceptional flexibility, high efficiency, and precise process control. Laser beam welding has the great advantage that it can be used outside a vacuum but in general it is only suitable for material thicknesses below 25mm. The process is suitable for the manufacture of tailored blanks of different steel qualities and material thicknesses. Another advantage is the low heat input resulting from the high energy density. By means of remote techniques, it is possible to use the effect of the laser beam over relatively long distances between the beam source and the welding position (up to 500mm). It is to be expected that laser beam welding will be increasingly used in automobile fabrication. It will also be utilized in the processing of plastics because of requirements with regard to the light absorption of the plastics to be processed [6-9].

### **2.3. Friction and resistance welding processes**

There has recently been a series of new developments relating to friction and resistance welding processes. Latest developments of friction welding machine technology have led to the use of the lateral relative movement of the parts to be welded so that the technique can be utilized for joining large sections which are not rotationally symmetrical. One special variant of friction welding is friction stir welding (FSW), which at the moment is used exclusively for aluminium and its alloys. The main problem slowing its application to other materials (e.g. steel) is the low stability of rotating tools [6]. The advantage of friction and resistance welding processes is that the welding is carried out below the melting temperature and thus the welding leads to only a slight metallurgical change in the base materials to be joined. The great forces needing to be inputted into the work pieces are disadvantageous and necessitate very sturdy clamping jigs. Friction stir welding is currently utilized in rail vehicle construction, the aerospace industry, and for the leak-tight welding of covers into hydraulic control parts. Resistance welding will continue to advance rapidly (with pressure from the automobile industry to weld higher strength steels and Al alloys) with improvement in inverter power supplies, improved process regulation or control, and improved quality assurance. Improvements in machine control and computer technology have made different process variants (flash butt welding, stud welding, etc.) more reliable [7,8].

### **2.4. Hybrid welding technology**

Hybrid welding is a combination of an arc welding and the laser welding in the same weld pool. Fundamental progress with regard to the development of combinations of various welding processes, i.e. hybrid welding, is to be expected. The combination of arc metal welding with laser beam welding has been introduced into practice at a particularly quick speed (shipbuilding and automobile construction), and is reflected in the expectation of a greater degree of utilization in practice. The combination results in very positive characteristics such as high energy density and low thermal load, high welding speed, deep penetration and high tensile strength, good gap-bridging capacity, and the possibility of the addition of filler metal and metal microstructure modification. It is possible to weld greater wall thicknesses in one pass, which gives considerable economic benefits no wand in the future. This process has been applied mostly in the welding of steel.

Specific advances will include continued development of dual- (or multiple-) beam welding, deep welding using higher power sources and special gas assists, further development of hybrid welding processes (like laser-GTA and laser-GMA, laser- PAW, laser-submerged, Laser-tandem). Beyond, but related to, welding will be continued development and application of targeted surface modification (i.e. heat treatment, glazing, texturing); cutting, drilling, and machining; and rapid prototyping. Similar advances will likely occur with plasma-based systems. Plastics welding (including welding of thermoplastic-matrix composites) will continue to advance as thermoplastics and thermoplastic-matrix composites continue to proliferate and advance. New processes include: high frequency welding, thermal impulse welding, hot bar welding, vibration and ultrasonic welding, and focused IR welding. Another trend will be toward the welding of polymer-coated materials (e.g. metals) for decorative and/or corrosion resisting applications [6].

In regard to thin steel sheet products new developed automotive materials such as Pb-free sheets coated with a Sn-Zn alloy for fuel tanks to minimize environmental pollution, Al-coated sheets and high-strength sheets [10,11] effective in reducing car weight and enhancing collision safety. Chromate free post treatment that minimize environmental pollution, pre-coated sheets effective in preventing environmental pollution, reducing costs through process have been developed [12]. Use of light weight materials e.g. aluminum and magnesium effective in reducing car weight, but steel has been found superior to them in terms of reliability and cost. Dissimilar materials structure partially using aluminum were also studied, and for joining steel and aluminum, methods such as friction spot joining, direct welding, soldering and welding using aluminum coated steel sheets were proposed [13,14].

### III. WELDING MATERIALS

When attempting to forecast future trends in welding technology, it is convenient to differentiate between traditional materials and advanced materials. The properties and functions of traditional materials are well known; therefore, improved performance can be best achieved by reducing the cost and increasing the quality of the joining process. It is commonly believed that this can be accomplished through automation and enhanced quality-control procedures. Whether a material or process is traditional or advanced depends on the

industry considered. For example, welding structural aluminum cannot be considered new in the aerospace industry, yet, it is an advanced application in automotive production. The change to a space frame automobile design will remove the structural redundancy afforded by current designs; thus, new joining processes will be required to overcome the limited quality of resistance welding. Brazing as well as laser, or conventional arc welding processes are candidates to handle the fabrication requirements of new automobile structural components.

The cost of many advanced materials is so high, and their properties so specialized, that they will only be used where they are essential. Consequently, products will contain more joints, a greater number of which will join dissimilar materials. Few traditional joining processes are practical in this situation; new part designs and joining processes will be required. Adhesives can always be used, but joint properties often place severe limitations on part design or function. Brazing will increasingly be considered, especially to join ceramics and metal-matrix composites. Low temperature metallic bonding using transient liquid phase technology will probably be extended to many more alloy systems. In the brazing process, a component of the brazing material or solder diffuses into the base material resulting in isothermal solidification of the filler material.

For every new material developed, joining processes must be restudied or developed to use the material effectively. Use of new materials will be limited by the capability to exploit the joining processes, rather than by the ability to design or produce such materials. The present direction of improvement of welded structures is a decrease of their weight and energy requirement in fabrication, and improvement of consistency and endurance. High strength low-alloy (HSLA) steels is the centre of application that widening the advances in this direction. At present, the fabrication of structures from HSLA steels without preheating is one of the main problems of arc welding. The results of researches into the problem of hydrogen welded joints have been generalized in [3,9,15,16]. The main tendencies of the optimization of properties of HSLA steels are i) the decrease in the content of alloying elements, ii) an increase in the number of combinations of micro alloying elements, iii) a decrease in the content of carbon, hydrogen, nitrogen, oxygen, residual elements, sulphur and phosphorus, iv) an improvement of the homogeneity and the level of mechanical

properties and improvement of the formability, weld ability and toughness of welded joints. These tendencies must be taken into consideration in the development of welding materials and welding technologies [3,17].

**IV. DEVELOPMENT OF MATERIALS**

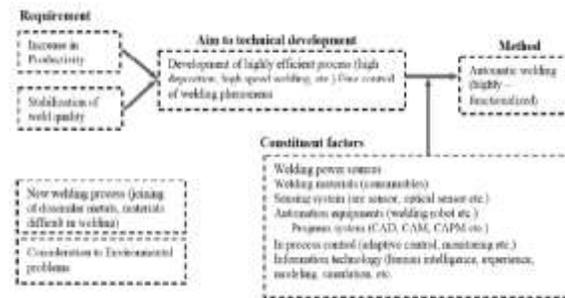
One fundamental need in the welding arena is a greater understanding of metallurgy as it applies to welded materials. Welding and materials engineers need to develop new materials and adapt existing materials so that they are specifically designed to be welded into world-class, fabricated products. Furthermore, there is a need to seek higher performance materials; match the material with the joining processes and advanced consumables of the application; develop more effective methods for welding traditional materials; increase the product design community's understanding of the science of metallurgy; stimulate development of product designs and new technologies and materials for welding; adapt certain alloys as weldable materials; increase access to information on the attributes of welding; integrate materials, processes, sensors and controls; and develop long-lasting, reliable, corrosion resistant materials that do not require pre-heating.

As materials are developed with increased strength, corrosion resistance, and other performance factors, welding of such materials can become more and more difficult. Special filler metals, pre- and post-weld heat treatment, and other techniques make welding feasible in many cases, but at substantially increased cost. The challenge is to make these materials as easy to join as simple carbon steels. Materials developed should have a corresponding alloy that can be welded. In the future, advanced computational methods will be used to engineer materials that can be welded reliably and consistently. With a new level of understanding of metallurgy, the entire welding sector will benefit and progress. Advances are needed in information technology in order to have the so called “smart materials” ready for use in the future. With computer chips embedded into the materials, there will be significant opportunities to program and control subsequent welding operations. The design of materials capable of adapting to increased speed and greater heat input with multiple electrodes is important for improvement in the efficiency of the process.

As the size of structures for low-temperature use becomes greater, there has been progress in the increase in the strength of steel. With the increase in the

tensile strength of hydraulic pipe steel used in, for example, hydroelectric power stations, very tough welding materials for use with 950 N/mm<sup>2</sup> grade steel have been developed. By the use of an ultra-low oxygen technology, in which the weld metal composition is Si – Mn- 2.5 – 3.5 % Ni – Cr – Mo and the oxygen content is lowered to 150 – 200 ppm, it is possible to achieve good low-temperature toughness at high strength. Furthermore, combinations of steel with light metals or plastics are being used ever more frequently in lightweight construction and the significance of nickel-base alloys is continuing to grow in the construction of power stations and aircraft engines [6].

Historical precedent has shown that development in materials science leads to societal progress. Essential to the creation of products from materials of the future, as much as in the past, will be the ability to join these materials into devices and structural elements, systems and assemblies. Without question, joining technology will have to evolve to meet evolutionary advances in materials. In the light of current trends, the main solutions in the area of development of new welding materials will be associated with optimization of the systems of alloying the weld metal in relation to the structure and properties of the parent metal, methods of decreasing the high content of hydrogen, nitrogen and other harmful impurities in the weld metal, development of effective technologies and materials for increasing the strength and ductility of welded joints, decreasing preheat temperature, and preventing the formation of different cracks, including those induced by hydrogen.



**Fig. 3. Requirements for welding production technology permitting its integration to automatization**

## V. EFFICIENCY AND PRODUCTIVITY

Efficiency is the extent to which time or effort is well used for the welding tasks. The search to reduce costs is driving industries to improve the efficiency of welding, by shifting equipment from manual to semiautomatic to fully automatic welding. By using robots, the human factors that reduce efficiency in welding are rectified. Increased productivity is achieved through a higher operator factor; a higher deposition factor; a higher welding speed; good, uniform and consistent quality; strict cost control through predictable weld times; minimized operator skill requirements; reduced training requirements; and better weld appearance and consistency of product.

Currently, automation is the single most important growth sector in the welding industry. The drive for higher productivity and reduced costs will keep automation at the forefront. Other reasons for the increasing use of automation include safety concerns and efforts to free welders from tiring, repetitive conditions and long-term exposure to fumes. Automatization and robotization are beginning to be taken as key technologies to secure improved productivity and consistent quality in welding, in addition to the above-mentioned measures to meet such narrow purposes as labor savings and unmanned work. Fig. 3 [9] shows the technical constituents needed to configure a welding system such that it provides improved productivity and highly consistent weld quality. It goes without saying that the arc phenomena in arc welding is a governing factor for developing high efficiency and high deposition, and for promoting the accuracy of welding performance control.

Every material has different weldability, and all types of welding processes are not able to weld all kinds of materials. Generally, however, one process can be deemed the most suitable for one type of material. Therefore, improved efficiency can be gained by choosing the most suitable process based on the heaviest of the materials that are going to be welded.

For economic reasons, the simulation of processes and properties is becoming a key factor in the application and further development of welding processes and materials. Those welding processes and materials which cannot be reliably simulated run the risk of no longer being used. Simulation of joining processes permits virtual testing and optimization of the welding

processes before production, permitting the planning and implementation of quality-assurance concepts prior to the joining process and assisting in the evaluation of commissioning, operation and repair issues. Simulations also provide information regarding necessary training of personnel for work piece fabrication, maintenance and repair. In the long-term, the objective must be to permit a universal concept for the simulation of the entire process chain on the basis of elements consisting of process simulation. In terms of further improvements with the increase in the size of structures and demands for efficiency, the search for better strength and toughness, and associated developments in steels, can be expected to continue. Because of this, the problem of how to control weld metal structure will continue to be of the greatest importance.

In terms of efficiency too, the requirements for greater speed and stronger adhesion can be expected to continue in all welding sectors and for all types of structure. One fundamental tendency is towards deterioration in the quality of welds due to the ever increasing speed and heat input. Optimization of the chemical composition of the weld metal to improve its characteristics and quality will no doubt help to address this problem, although this will inevitably involve with the need for advances in knowledge of welding metallurgy.

In order to achieve a step change improvement, it is important that novel approaches should abandon previous, fixed ideas to transcend the accepted framework of weld metal specifications. In light of this demand, information derived from any failures will be incorporated into future, improved designs of welded products. Accurate predictions of the performance of welds and weld systems and the capability to model and analyze welded joints will be an important development in improving their quality. In recent years, quality has been a major concern and although most welded products are already produced to meet a high standard of quality, a movement is underway by the industry to insist on superior "six sigma quality" in all its welded fabrications. The term "six sigma" refers to a weld that is highly reliable and is a quality usually demanded for such critical products as aircraft and bridges. This level of quality requires that better than 99.999 percent of all welds will exceed the standards given [18].

## VI. EDUCATION, SAFETY, AND HEALTH

For welding to achieve its potential as a preferred state-of-the-art manufacturing process, the scientific and engineering principles behind welding must replace the so – called “art of welding”. A part of the Solution may be more effective apprentice programs for welders and technicians. It is to be expected that as apprenticeship and certification programs become more rigorous, welding as a vocation will gain a higher level of prestige. Successful implementation of modern welding techniques demands that the right individuals are running the work, and that they have a sufficiently comprehensive understanding of the welding process and material.

In welding situations, there are environmental burdens originating from the process, due to dust arising during the welding which may be harmful to health. Therefore, measures must be taken to protect the health of welders. Increased concern for health and safety issues mean that potential hazards will need be addressed, such as burns, welding fumes, excess noise, electric shock, and falls. The growth of environmental consciousness means that the future can expect to see increased use of so-called green techniques throughout the life cycle of welded products, and insistence on the use of welding utilizing energy-efficient and environmentally sound advanced technologies. It was reported in [19] that companies need to work to ISO 14001 in order to install an environmental management system if they want to remain a supplier, and to reduce the impact on our environment.

Increased demand for natural resources suggests that there will be pressure for the development of methods for welding in hostile environments, e.g. in deep water oil rigs and in Arctic conditions.

## VII. MANUFACTURING INDUSTRIES

Welding can be performed in different environments, in air, underwater and in space. It is also applicable in different areas and industries such as construction, petroleum industries, aircraft industries, transportation, machine manufacture, household manufacture, and repair and maintenance. Table 1 shows the general trends and key needs in a number of manufacturing industries. Analysis of the drivers and needs of the industries gives a strong indication as to the

expected trends in technology that will be seen in the next 5 years.

## VIII. CONCLUSIONS

Although this paper does not cover all developments, and the discussions are necessarily limited, the technologies discussed are, however, to some extent, all already practiced in industrial applications. The directions of future technical developments are relatively clear, as are the challenges facing the welding sector. The main findings can be summarized as in the list below.

1. Materials of the future will be designed to be weld able as part of the total integration of welding into the manufacturing cycle. They will also be energy efficient and environmentally benign. Smart materials with a computer will help with materials processing at any point in the life cycle of the component.
2. The use of modeling, systematic process selection and procedure development, and non destructive examination technologies will ensure that welding can be part of a *Six Sigma* quality Environment.
3. Improved education and training will increase the knowledge base of people employed in the welding industry, at every level, enabling them to make decisions that result in utilization of the best welding technology for each application.
4. There will be a trend towards higher levels of reliability and higher-quality requirements. The trend towards automatic welding and automation in welding will accelerate.
5. To realizing high-quality joints, it is important to develop high efficiency and easily practicable welding processes. This requires joining through thorough studies of welding equipment, practice, and consumables.
6. Gas shielded arc welding will retain its dominant position, and the latest research supports the application and further development of these processes. Resistance welding processes will hold a dominant position due to their process performance and productivity. However, they will become less prevalent in some applications, in particular because of the increased use of mechanical technology and adhesive bonding.

7. The necessity of using hybrid welding processes to a greater degree is shown in the potential of using hybrid welding in welding thick sections. This is reflected in the expectation of greater use of hybrid welding in practice.

8. Welding methods such as laser welding, laser arc hybrid welding and friction stir welding will become far more significant as a result of the rapid transfer of findings from research to application. Welding automation is very suited to mass production and welding in certain critical Environments and positions. Finite element analysis simulations would be a very handy tool for designers and companies to simulate welding processes and evaluate parameters prior to building the physical test set up.

9. Based on today strands, the joining engineer of the next decade will be faced with the task of developing processes for new materials in much shorter lead times. Components will be smaller; structures will be more three-dimensional with less redundancy, requiring greater reliability; and more dissimilar materials combinations will be required.

10. Steel will remain the main structural material. As previously, low carbon and low alloy steels will be used on a large scale. Their quality, mechanical properties and weldability will be improved as a result of decreasing the content of harmful impurities, finding new alloying systems, increasing the sensitivity of heat treatment, and increasing corrosion resistance in different media. Special attention will be given to the development of new types of high strength low alloy steels, including those with a very low carbon content, heat resisting steels, steels of structures operating at low climatic temperatures, cryogenic applications and high alloy steels for different purposes.

11. Further work will be carried on the development of aluminum high strength alloys, titanium alloys and other types of new structural materials.

12. The design of welding materials may be considered to play the most important role in improving the quality of the welds and maintaining the reliability of structures. The training of welding technicians with this approach will be of the greatest future importance.

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