20주년 기념 특집 : 해외 용접기술 동향

Vision for Welding Industry in USA

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Abstract

용접기술은 두 가지 재료를 효율적으로 신뢰성 있게 접합시킬 수 있기 때문에 다른 어떤 기술보다 널리 사용되고 있으며, 높은 부가가치를 가져다 준다. 용접계에서는 용접이 국내 산업에 아주 중요한 역할을 담당하고 있다고 생각하고 있으며, 이제 21세기에 접어들어서 우리 용접계의 현위치를 파악하고 새로운 장을 열어야 할 때이다. 미국에서도 이러한 준비의 일환으로 에너지성(Department of Energy)의 주도하에 Welding Vision 2020라는 명제를 걸고 용접분야의 장래에 대한 심포지움과 토의를 하였다. 이 토의의 중심 주제는 20년 후의 용접계의 위상을 그려보며 장기적 연구 분야, 산학계의 정책 방향 등을 모색하였다. 여기서 모아진 의견은, 용접계의 발전적인 진전을 위해서는 향후 2020년까지 다음과 같은 숙제들을 극복해야 된다는 것이었다.

- 많은 산업분야에서 용접이 생산 분야의 주된 작업으로 인식시키는 것
- 용접이 용접 기능사의 재능에 의존도를 줄이고 과학적인 용접 기술 도입과 용접 기능사의 체계적 훈련
- 용접 작업환경 개선
- 용접을 과학적 고기술이라는 것으로 일반인들의 인식을 변화 시킴
- 신소재 개발연구시 용접이 같이 고려될 수 있는 환경 조성
- 훌륭한 인재 양성 및 재교육

본고에서는 미국 용접계에서 분석한 자료들과 장래 연구되어져야 할 방향 및 분야들을 소개하고 현재 진행중인 자료 수집 및 분석의 진행 상황 및 용접계의 현 위치를 파악할 수 있는 몇 가지 자료들을 소개한다. 아울러, 용접계에서 리더쉽을 발휘해야 될 분야중의 하나이며 현재 많은 전문연구가 필요한 용접 역학(Welding Mechnics) 중의 용접부의 안정성 평가(Integrity Assessment of Welded Joint)에 대한 과제와 연구 동향을 소개하고자 한다

1. Introduction

Welding is a critical technique for joining of materials in the nation's major manufacturing industries. Since 1998, leaders in welding industry have defined vision of the issues and opportunities that will face in 2020. In developing this vision document, more than 25 senior managers and respected experts from various segments of the welding community met to begin a dialog about the future of the welding industry. They were brought together to develop a long-range business plan for their industry that would identify how it would meet the needs of manufacturers, of the marketplace, and of society in 2020. In essence, these decision makers created an ideal vision of the state of their industry in 20 years, and the strategy to reach it.

In June 1998, the U.S. welding industry took the first step in pursuing a research partnership with the U.S. Department of Energy (DOE) to demonstrate, evaluate, and accelerate new technologies and scientific insights that address the specific needs of the welding industry. That month, the industry held a workshop whose results were used to prepare the *Vision for Welding Industry*, a document that presents a unified, strategic vision of the future of the welding industry[1]. This document identifies the major challenges and barriers the industry is likely to face over the next several decades and sets broad performance targets for the following areas:

- **Cost and productivity** : Reduce the cost of welding by 33% and increase the use of welding by 25%
- **Process technology** : Increase the use of welding in manufacturing and construction
- **Quality standards** : Assure that welding can be part of a six-sigma quality environment.
- **Materials performance** : Develop new welding

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technology along with new materials

- **Education and training** : Increase the knowledge base of people
- **Energy, environment, health and safety** : Reduce energy by 50% through productivity improvement.

The vision process is the first of a flexible, three-step approach to technology development. Based on the performance targets identified in the vision, the industry will develop a detailed research agenda, known as a technology road map. Industry technology leaders began developing a "Road Map" for dealing with challenges and opportunities faced by our industry in an increasingly competitive global environment.

The vision describes the issues and opportunities facing the US welding industries through the next twenty years. The strategic goals outlined in the vision are ambitious and will require hard work and commitment by the industry. The advisory committee identified four major industry segments that rely heavily on welding. They are heavy manufacturing industry, aero space industry, petroleum/energy industry and automotive industry. Specific goals and action plans are proposed for the industry segments based on several workshops by the industry technology leaders.

A major economic impact study cosponsored by AWS, Edison Welding Institute (EWI), and supported by US Navy, State of Ohio, US Department of Commerce, and major companies was kicked off [2]. This two-year study will determine the economic impact of welding on the United States economy. The objective of this study is to break a paradigm about welding - those of us who are heavily involved in welding believe strongly that much of our gross domestic product is directly dependent on welding.

Furthermore, continued advances in the field of welding are necessary to achieving further increases in productivity that makes our economy strong. Yet, despite the intuition, anecdotal information and fragmented analyses, the completing quantitative information does not currently exist to support the strong beliefs of the many dedicated workers in the field of welding. This economic impact study would prove the justification for strategic actions to further develop this critical field is not currently available.

Integrity assessment of welded joint becomes more and more important to the industry. Structural integrity assessment also provides welding engineers with the overall perspective of integrated structures and pressure equipment [3,4]. Fitness for service is a fast growing technology to assess safety of the welded system. Fitness for service (FFS) assessments are multi-disciplinary and quantitative engineering evaluations which are performed to demonstrate the structural integrity of an in-service component containing a flaw or damage in a welded structure. API RP 579 and BS 7910 provide the state-of-the-art guidance for conducting FFS of welded structures [5,6]. The guidelines can be used to make continue-to-operate assuming weldment can have tolerable flaws depending on its service condition. Integrity assessment includes residual stress prediction and measurement, weld microstructure modeling, fracture mechanics and inspection technique.

2. Vision

2.1 Vision for Welding Industry

" In 2020, welding continue to be the preferred method by which metals and other engineered materials are joined into world-class products. US industry will be the world's leading source of these cost-effective, superior -performing products by virtue of its leadership in joining technology, product design, and fabrication capabilities, and globally competitive workforce."

This vision clearly states that the society expects to maintain its superiority in joining technologies in the future. Technologically advanced welding and joining processes will be integrated into the design and manufacture of high quality products and structures. The research priorities contained in this technology road map should help guide the welding industry in accomplishing its vision.

Major challenges will be overcome by the Welding Industry by the year 2020:

- Integration of welding into the product life cycle: Welding should be a part of integrated system. Welding should be integrated into design, manufacturing, and material selection. Traditionally, materials have been developed without considering if and how they can be welded. Weldability should be considered during the development of new materials. Integration of weldment into the product of life cycle, and accurate

models of life-cycle costs will help customers better understands the relative cost and value of the welding. Fatigue of welded structure is a good example for integration. Whereas, creep life assessment of the welded joint has not been well integrated despite number of failures experienced at or near the weld.

- Quality of welded product:
  While most welded products are produced to meet high standards of quality, the industry is moving to ward "six-sigma quality". Improving weld quality lowers production costs and consumption of natural resources. Integrity assessment and standards play a role in determining weld quality. Effective integrity assessment should help eliminate unnecessary repair or replacement, thereby improving life-cycle costs.
- People-attracting and maintaining a skilled, educated workforce:
  Like many other similar industries, welding has had difficulty attracting and keeping good workers. A skilled and educated workforce is critical to the survival and growth of welding. The perception of welding will continue to change as education and training increases the awareness of newly developed welding technologies. Public relations effort may be one avenue for improving the image of welding. Education and training will be need for all levels of workforce. With the current trend toward down sizing and merges, the welding industry should be able to provide more technology transfer both nationally and globally.
- Transition welding from art to science
  Unfortunately, many of existing welding practices are based on experiences. It requires transition of welding from an empirical-based to a physical-based process. A major stumbling block is a lack of understanding of the fundamental physics of the materials used in the welding and welding process. The comprehensive physical-based model would cover the entire life cycle of the welded product. Welding processes based on engineering analysis, numerical modeling, and computer-based automated manufacturing will be widely used in 2020. The model will also facilitate the move to process-based quality for welding. Integrity assessment and life time prediction would be integral functions of the model.

2.2 Goals for welding industry

Specific goals and research needs in the four industry segments (Heavy Industry, Aerospace, Petroleum/ energy, and Automotive) were developed.

Heavy Manufacturing Industry

Heavy industry includes manufacture and maintenance of ships, off-shore platforms, train, farm vehicles, construction and mining equipment, bridges, buildings and similar structures utilizing welding. Advances to welding processes for these applications have not kept pace with other technological developments. Research to develop welding processes and integrated manufacturing systems will improve cost effectiveness and cost of welding. Key R&D topics identified by the technical committee were as follows:

- New welding processes and filler metals
- Inclusion of weldability and manufacturability in new material development
- Concurrent product/process simulation and development
- Better forum to identify research need

Aerospace

Aerospace industry includes manufacture of aerospace products such as aircraft, engines, missiles, and rockets. This industry faces tough pressure for new products to be more affordable, both in initial production costs and overall lifecycle costs. Safety considerations, however, mandate that this cost-effectiveness be achieved without compromising quality. The integration of weldability into the development of new, lighter alloy will be a key component of this success. Key R&D topics identified by the group are as follows:

- More comprehensive scientific understanding and modeling of welding
- Process understanding that improve product quality to the six-sigma level.
- Capability to predict distortion and residual stress

Petroleum /Energy

The extraction of oil and gas and the refining of petroleum rely on welded equipment ranging from pipes and tanks to offshore drilling structures. Increasing emphasis is given on deep-water applications. Safety of the pressure equipment will require integrity assessment

of the aged equipment. The welding users in this industry must partner with metal producers on the development of new alloys to ensure their weldability. Better data on weld performance, along with new integrity assessment techniques and updated integrity standards, will reduce maintenance requirements and improve the cost-effectiveness of welded structures. Key R&D topics identified by the group are as follows:

- Smarter welding equipment
- Weld process and product modeling
- Technologies for fitness-for-service, life extension and risk based inspection
- The ability to model residual stress and distortion in complex structures
- Weldable alloys that reduce pre and post-weld heat treatment

Automotive

The automotive industry sector includes all on-road and light versions of off-road motor vehicles. Companies within this sector include the original equipment manufacturers (OEMs) and their tiered supplier base. In the United States, several OEMs operate facilities (including "transplant") with thousands of companies supplying components to typically numerous OEMs or other suppliers. Outsourcing of components has been the trend with OEMs over the past decade. Key R&D topics identified by the group are as follows:

- Welding processes for lightweight alloys
- Predictive tools for welded structural integrity and distortion
- Processes to economically join coated materials
- Welding processes for tubular structures
- High confidence modeling tools

3. Welding-economic impact study

The objective of this study is to provide a clear understanding of the true scope and impact of the field of welding/materials joining on the nation's economic well-being. The goal of this study is to answer critical questions that include:

1. How much of the current US Gross Domestic Product is represented by the welding industry?
2. What has been the contribution of welding to improving the productivity of the US economy?
3. What industries could benefit most from further gains in welding quality and productivity?
4. How can the strategic objectives of key government bodies benefit from this knowledge?

The benefits arising from this study include:

- Compelling cases for future public and private investments in welding technology improvement by providing tools to estimate the impact of specific investments.
- Clear evidence of the importance and financial value of welding in their manufacturing operations to all levels of management.
- Tools to help strengthen the public's awareness of the importance of this field of manufacturing.
- Help in attracting high potential young people to the field as engineers, scientists and welders.
- A factual basis for the intuitive views of workers in the field regarding the importance of welding.
- This information will be useful to community and state education programs, economic development initiatives and overall prioritization of investments by the scientific, technical and industrial communities.
- Definite benchmarks for the future measurement of the progress field

4. Economic impact study - heavy manufacturing industries

The first economic impact study was completed for heavy manufacturing industries (HMI). The objectives were to determine the economic contribution and productivity of welding in US industries and identify where the greatest opportunities exist to further improve welding productivity. Eight divisions in the HMI sector were defined in this study:

(1) Armored Vehicle, Military Tank and Tank Component Manufacturing
(2) Construction & Mining Machinery Manufacturing
(3) Engine, Turbine, and Power Transmission Equipment Manufacturing
(4) Farm Machinery & Equipment Manufacturing
(5) Oil and Gas Field Machinery Manufacturing
(6) Power Boiler, Heat Exchanger, and Heavy Tank Manufacturing
(7) Railroad Rolling Stock Manufacturing
(8) Ship Building and Repair

4.1 Data Collection Instrument

Data collection guides were designed rigorously to ensure validity and reliability. The data were gathered using both the Top Down and Bottom Up approaches. Initially, the survey team conducted interviews with industry experts to understand key factors. The top down approach utilizes information from the Office of Strategic Industries and Economic Security (SIES) of the U.S. Department of Commerce Bureau of Export Administration which include 500 companies in the HMI sector. Surveyed companies included 100 largest U.S. manufacturing establishments and 400 smaller firms in the HMI sector.

Following a data collection protocol developed through top down process, in-depth interviews and on-site facility tours were completed with nine firms in the HMI sector-Bottom Up approach. The purpose of these interviews and tours was to investigate the economic contribution of welding within these industries based on the contribution of welding to representative commodities. Table 1 shows companies responded to written survey.

Table 1 Respondent representation of industries

Industry	No. of responded companies	Percentage of total value of responded
Armored vehicle, tank and tank comp.	3	93%
Ship building and repair	21	63%
Railroad	4	46%
Power boiler rolling stock	42	42%
Farm machinery	32	38%
Construction & mining	27	34%
Oil & gas field machinery	9	19%
Engine turbine	9	5%
Industrial machinery	27	1%

4.2 Results

In 1999, combined value of shipment or sales by HMI sectors totaled $144.7 Billion. The total cost of production was reached to $108.2 Billion. Table 2 illustrates total shipment, total cost of production and welding related expenditures. As shown in the table, total welding related expenditure was $7.5 Billion. This represents an average 7% of the total costs of production in this sector. It is a significant portion when considering other major costs of material and design etc. Ship building and repair and Construction & Mining Machinery industries shows the highest percentage of welding-related costs to total costs at nearly 12% and 11%, respectively.

Table 2 FY 1999 total value and costs of production and welding related expenditures
unit: Billion US dollars

Industry	Total Sales	Cost of Production	Welding related expenditures	Ratio of Welding-related/cost
Ship building and repair	11.0	8.85	1.06	11.9%
Construction and mining	25.7	20.0	2.18	10.9%
Railroad rolling	9.66	7.56	0.69	9.1%
Industrial machinery	36.5	26.5	1.88	7.1%
Power boiler &HE	8.40	6.42	0.54	8.4%
Farm machinery	11.8	9.32	0.49	5.2%
Oil & gas field machinery	5.69	4.16	0.16	3.9%
Armored vehicle, tank	1.08	0.76	0.017	2.2
Engine, turbine	34.9	24.6	0.53	2.2%
Total for HMI	144.7	108.2	7.55	100%

Table 3 provides an overview of the proportion of welding related expenditures in each of the five categories i.e., labor, materials and consumables, energy, capital expenditures and other. The table clearly indicates that labor cost is the highest contribution of the total welding expenditures. The data illustrates the importance of labor resources and training welding specialists. There is also a strong indication, for most part, that capital expenditures are not properly utilized for investments that might reduce labor costs tremendously. There is also a strong positive statistical association between expenditure for welding-related labor and energy costs. Efforts to reduce energy costs must be based on improving productivity, which is often-times not effectively measured or managed in these industries.

As shown in Table 3, welding-related labor costs represent the largest portion of total welding-related costs in every industry studied. Overall, welding-related labor costs totaled $5.4 Billion in 1999 - an average of 16% of total labor costs in this sector. Railroad Rolling stock and Construction and Mining manufacturing

Table 3 Proportion of welding related expenditures in HMI secto

Industry	Total welding related expenditures ($Billion)	Poportion of expenditures for (unit %)				
		Labor	Materials	Energy	Capital	Other
Construction, mining	2.28	54.3	35.4	1.2	4.5	4.7
Industrial mach.	1.91	81.	11.8	5.6	1.3	0.1
Shipbuilding repair	1.07	69.3	27.7	1.8	1.4	0.3
Railroad, rolling	0.74	76.9	13.0	2.6	6.7	0.7
Power boiler, HE	0.56	48.4	41.5	4.3	3.9	1.9
Engine turbine	0.56	81.5	8.5	1.8	5.1	3.2
Farm machinery	0.53	75.6	11.6	3.4	8.2	1.2
Oil & gas field	0.18	82.2	8.4	1.3	8.0	0.1
Armored vehicle	0.017	87.0	5.1	0.3	3.5	4.2
Total/average	7.85	74.0	17.3	2.7	4.4	1.7

showed the highest proportion of welding-related labor costs versus total labor costs and they are 29% and 27%, respectively. Shipbuilding industry showed 17% of the total labor costs.

4.3 Major Findings and Opportunities for Improvement

Major findings and observations are listed after carefully examining the data for the HMI sector. While studies for other sectors are underway, several observations and opportunities were listed.

Observations

- Welding represents a substantial contribution to the US economy :
- Most HMI firms have not studied and have minimal understanding of the economics associated with the use of welding related process: In the majority of these firms studied, welding is reviewed simply as a necessary production input for which costs must be controlled. Consequently, most who do evaluate welding costs do so with the objective of reducing costs rather than increasing productivity.
- Most firms involved in HMI don't adopt at evaluating the complete manufacturing process and the role of welding in that process: Welding is commonly viewed as a production function to be controlled in order to minimize the cost of this function. Firms recognized for quality and productivity view welding in a broader perspective-as a contributor to providing added value in the final product. These firms under stand the economics associated with welding and how the use of welding applications can contribute to the overall value of the final product. Beginning with product design and advancing through production facility design, and production fabrication, welding is viewed as an integral part of the complete manufacturing process, not a cost center to be controlled.
- There are no consistent measures of welding productivity currently being used by HMI.
- The shortage of qualified operators, technicians and engineers in the field of welding is a potential threat to those industries that rely on welding.

Opportunities

- Develop more in-depth understanding of the economics of welding: Change and adoption of more productive welding applications will only be driven by clear economic gains. A national effort, led by the welding industry, will be necessary to help manufacturers understand, in real dollars for specific manufacturing operations, how improved welding productivity can add value to the final product.
- Improved educational opportunities in the field of welding: One of the key factors limiting welding productivity is to rely on the skill level of many practicing welders. Welders with limited skills are more likely to produce defective welds, which result in decreased productivity. Decline in trained welding engineers has resulted in productivity decrease.

- Share knowledge of productive practices: While sharing knowledge about welding productivity improvements does take place through both formal and informal means, this sharing of knowledge is not systematic, particularly between industries. Opportunities for cross-industry sharing of productivity improvements should be supported.
- Continue the development of common national system of standards, assessments and certification.
- Develop cooperative research and development programs: both government/industry and industry/industry - that emphasize 'real world' applications of semi-automatic and automated processes to be more productive.
- Adopt more productive practices already identified through research efforts.

Acknowledgement

The author wish to express his sincere gratitude to Mr. Fritz Saenger, former EWI director, for his support and providing information and AWS for initiating this study.

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