2005 Annual Report

Advanced Metalworking Solutions for Naval Systems That Go in Harm's Way

National Center for Excellence in Metalworking Technology

A ManTech Center of Excellence

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The NCEMT is helping the Navy ManTech Program achieve its goals by developing advanced metalworking technologies and applications. In 2005, ManTech again focused on its Integrated Systems Investment Strategy to better support Sea Power 21 and DoD's emphasis on transformation. In turn, the NCEMT aligned its portfolio and made significant progress executing projects concentrated on the three initial PEOs / platforms comprising the strategy: PEO (Ships) for DD(X); PEO (Carriers) for CVN- 21; and J-UCAS (Joint-Unmanned Combat Air System). The NCEMT also answered ManTech's call for lean operations by making noteworthy reductions in infrastructure and administrative costs.

Some important changes have recently occurred in the NCEMT Program, notably a new contract and a new center name. On October 14, ONR awarded *CTC* a five-year, Indefinite Delivery Indefinite Quantity contract to manage and operate the program. With the contract award, the name of the center has changed to the Navy Metalworking Center, signifying ManTech's continued emphasis on efficient operations and practical metalworking applications and processes. The new contract enables the NCEMT to maintain its momentum, continue working with project teams and focus on project implementation.

On a somber note, the NCEMT lost its Program Officer of nearly a decade when Ed Coyle died tragically in a motorcycle accident. Greg Woods, a long-time advocate of the ManTech Program, is the new Program Officer. Greg and Dan Winterscheidt, the Program Director, have been working together to establish new relationships and to identify projects that will benefit from the expertise and resources offered by the center.

It's an exciting time for the ManTech Program. I have confidence in the leadership and staff of the Navy Metalworking Center and believe that they will continue to strive for technical excellence and successful project implementation in the coming years.

John U. Carney
Program Director
Manufacturing Technology Program
Office of Naval Research

"The Navy has both a tradition and a future—and we look with pride and confidence in both directions." This 1961 quote by Admiral George Anderson, Chief of Naval Operations, captures very well the sentiment of the NCEMT as we report on the progress and accomplishments of the past year and look forward to the new challenges and partnerships that will be presented by our new contract.

Our project portfolio reflects both the new direction in the administration of the ManTech Program and the NCEMT's response to the call for change. ManTech requested a reduction in infrastructure and administrative costs, and the NCEMT took action to significantly reduce expenses, which resulted in maximum resources available for project execution and implementation.

In 2005, ManTech continued to employ its Integrated Systems Investment Strategy that supports critical naval weapons platforms, including CVN-21 and DD(X). The NCEMT worked with the Future Aircraft Carriers Program Office, NAVSEA, Carderock, Northrop Grumman Newport News and other industry partners to address the Navy's need for high-strength, light-weight materials that reduce weight and lower the center of gravity, and processes that optimize welding techniques and reduce weld distortion.

In support of DD(X), we continued working with NAVSEA, Carderock, Northrop Grumman Ship Systems, Bath Iron Works, the Navy Joining Center, the Institute for Manufacturing and Sustainment Technologies and other partners to focus on requirements for high-productivity welding techniques, automated manufacturing processes for steel plates and special hull treatments.

For the M777 Lightweight 155mm Howitzer, we worked with the Joint Program Management Office to develop manufacturing processes, which are being transitioned into production, that decrease part count, and forming technologies that reduce manufacturing cost and material waste. This annual report also highlights projects that are funded by other DoD organizations, such as our Combat Vehicle Research efforts for TARDEC and our work with NAVAIR and Sikorsky Aircraft Corporation on the H-60 Seahawk helicopter.

Some of you may have noticed that, with the award of the new contract, we changed the name of the center to the Navy Metalworking Center. Rest assured that while the name has changed, we remain steadfast in our commitment to develop and implement advanced metalworking solutions for naval systems that go in harm's way.

Daniel L. Winterscheidt, Ph.D.
Program Director
Navy Metalworking Center

The NCEMT, along with its government and industry partners, remains focused on ensuring the expeditious development, verification, and implementation of world-class capabilities for the CVN-78 21st Century aircraft carrier, the first ship in the CVN-21 Class. Key projects underway include work with high-strength steels and welding enhancements that will aid in the advanced design of the new carrier—the first "flattop" redesign in 40 years.

Aircraft Carriers

Before projects are launched, careful consideration is given to the expected impact on cost, performance, and the implementation timeline of CVN-78. The NCEMT joined with Northrop Grumman Newport News (NGNN); Naval Sea Systems Command (NAVSEA); the NAVSEA Future Aircraft Carriers Program Office, PMS 378; material suppliers; and others to complete a concept exploration project in which a series of project ideas were evaluated for potential implementation in support of CVN-78. These project concepts include the evaluation and testing of one-sided welding of HSLA-65, thick-section HSLA-65 welding, hot/cold forming limits for HSLA-65, flame straightening, LASCOR panels, friction stir welding, and a fire-resistant door. Specific project tasks will be integrated into the construction schedule for CVN-78, as needed.

Building on its successful experience with a number of high-strength steels, the NCEMT is working on two projects that involve manufacturing issues and the optimization of high-strength and toughness steels. The projects are determining whether the steels can achieve a 400-long-ton weight reduction as well as a lower center of gravity for CVN-78 by reducing plate thickness while retaining or exceeding material performance and protection levels. Both projects are managed by multifaceted Integrated Project Teams (IPTs) whose members, in addition to the NCEMT, include NAVSEA; the Naval Surface Warfare Center-Carderock Division, (NSWCCD); NGNN; Mittal Steel USA; the Navy Joining Center (NJC); and QuesTek Innovations.

The NCEMT is working on several advanced metalworking projects pertaining to the development of CVN-21, the Navy's future aircraft carrier.

Several steels are under study. The IPT is performing extensive metallurgical evaluations, investigating heat treatments, evaluating hot and cold forming effects, and verifying magnetism effects to determine how to optimize the steels for desired characteristics. Based on its findings, the IPT will recommend fabrication procedures. The ultimate goal is to help prepare shipyards for the implementation of the new steel by identifying potential issues earlier in the development stage. By studying manufacturing issues such as forming, dimpling, and magnetism effects, while further evaluating the metallurgical aspects of the steels, risk should be reduced regarding successful implementation of the high-strength and toughness steel selected for incorporation on CVN-78—saving time and money.

Titanium Components Offer Multiple Benefits

Another project underway to impact the weight of CVN-78 involves developing suitable manufacturing techniques for titanium naval components. Along with NAVSEA, NGNN, NSWCCD, and the NJC, the NCEMT is working to identify cost-effective titanium candidate components for CVN-78 and other ship classes. Titanium exhibits excellent specific strength, corrosion resistance, and fracture toughness properties. By substituting titanium alloys for steel, the expected benefits on aircraft carriers are reduced structural weight, a lower center of gravity, increased loading capacity, reduced maintenance, and decreased life-cycle costs.

Welding Advances Essential to CVN-78 Success

Reducing weld distortion and minimizing subsequent associated rework will decrease cost and limit schedule impact on CVN-78, and the technology to accomplish this is being developed by the NCEMT; NGNN; and NAVSEA Future Aircraft Carriers Program Office, PMS 378. To eliminate weld distortion of CVN-78 heavy plate erection units, fabrication parameters are being established that will produce foundation assemblies that meet flatness requirements. The NCEMT and its partner are building a mock-up foundation assembly to evaluate and predict distortion for the U.S. Navy. The technology developed under this project will be directly implemented in the production of CVN-78.

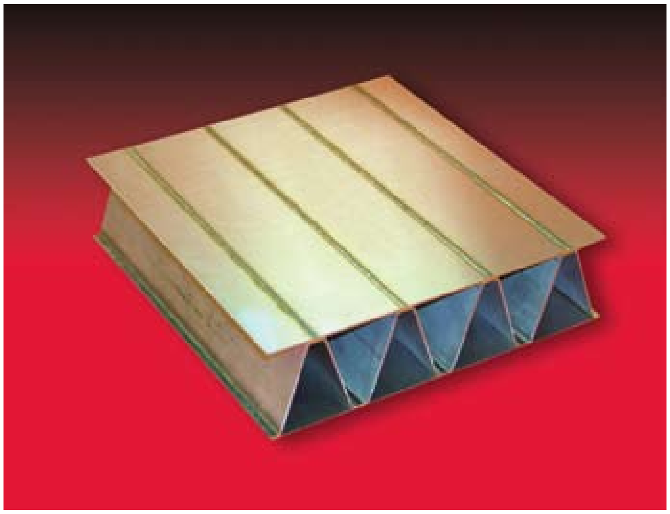
Another project expected to result in direct technology transfer to the CVN-78 involves the development of a new MIL-101T-"X" flux cored welding electrode for use with 75% Ar-25% CO_2 shielding gas. This cost-effective, low-fuming electrode will minimize human exposure to manganese fumes without increasing porosity or diffusible hydrogen content, while still meeting NAVSEA requirements and shipyard usability characteristics. Successful implementation will enhance productivity and improve access to tight areas by eliminating the need for shipyard welders to wear respirators in some enclosed spaces.

Developing New Manufacturing and Testing Practices

Two diameters of the MIL-10718-M electrode, which are used for all shielded metal arc welding (SMAW) in HSLA-100 and HY-100 steels to meet ballistic performance requirements, must be consistently available for CVN-78 fabrication. The NCEMT is a member of an IPT that is optimizing 1/8-inch diameter MIL-10718-M electrodes and developing 3/32-inch diameter electrodes. The NCEMT is working with two electrode manufacturers to develop and verify successful manufacturing and testing practices for the two electrode diameters. The manufacturers are providing multiple lots of each size electrode to NGNN and General Dynamics Electric Boat—the systems integrator for the Virginia-Class submarine—for verification of operating characteristics, weld metal mechanical properties, and welder appeal. To date, the vendors (ESAB and Lincoln Electric) have successfully produced 1/8-inch MIL-10718-M electrodes, and both shipyards were very satisfied with the quality and consistency of the electrodes.

Working with IPTs to Achieve Design Goals

The NCEMT is working with IPTs that are achieving results, responding to customer needs, and contributing to the ultimate success of the new aircraft carrier. CVN-78 design goals call for weight and center of gravity reductions, and another project designed to help achieve these goals is a study to enhance LASCOR technology. Stiff, lightweight, metallic-sandwich panels called LASCOR (LASer-welded corrugated-CORe) panels may be a viable alternative to support weight-reduction efforts; however, design requirements and fabrication experience are not yet sufficient to enable use in critical applications. Also, joint and stud attachments to the ship structure, manufacturing fabrication



Stiff, lightweight, metallic-sandwich LASCOR panels may be used to reduce weight and life-cycle maintenance costs.

procedures and shipyard repair methods have yet to be established. The NCEMT is partnered with a multifaceted IPT, including NAVSEA Future Aircraft Carriers Program Office, PMS 378; NSWCCD; NAVSEA; the NJC; Applied Thermal Sciences; the Institute for Manufacturing and Sustainment Technologies (iMAST); and NGNN, to evaluate the viability of LASCOR technology.

If LASCOR technology can be implemented on CVN-78, an overall weight savings of 100 long tons may be obtained. Other potential benefits include reduced life-cycle maintenance costs and increased ship compartment useable volume. LASCOR is also being designed so that modular fabrication using conventional welding methods can be applied to simplify installation.

Promising work on projects such as these and many others will come together to ensure that, when CVN-78 joins the fleet, it will sail as the centerpiece of the U.S. Navy's forward presence.

The NCEMT is focused on delivering outstanding service through a dynamic, customer-centric approach to project management, ensuring both client satisfaction and technical excellence.

Ships and Submarines

The NCEMT led an Integrated Project Team (IPT) that developed high-strength marine-grade fasteners that are expected to last for the life of the submarine—improving reliability and reducing life-cycle costs by $220,000 per application, per year, per submarine. These fasteners, which will also result in reduced weight for the Virginia- and Seawolf-Class submarines, are expected to be implemented in October 2006 on the Virginia-Class submarine.

DD(X) Metalworking Needs

The NCEMT is working with the Navy Joining Center (NJC), Northrop Grumman Ship Systems (NGSS), Bath Iron Works, and other IPT members on several projects involving metalworking enhancements for the U.S. Navy's new DD(X) Class multi-mission destroyer.

Building the next-generation destroyer requires cutting, forming, and welding steel plates into shapes that fit into a complex structure with a minimal number of plates and welds. The NCEMT has been working to develop an automated thermal plate forming system to reduce construction costs while improving the dimensional accuracy of DD(X) formed hull plating. Although this project was suspended prior to completion, it is anticipated that the technology developed under this initiative has the potential to increase thermal hull plate forming throughput by 100 percent and decrease direct labor costs by 50 percent.

New high-productivity welding processes for large, thick-section, high-strength steel structures have been implemented in the fabrication of the second and third Engineering Test Modules at NGSS as a result of a joint NJC/NCEMT project that will also enhance survivability for the DD(X). This effort is expected to result in a reduction of over 14,400 hours in weld labor per DD(X), diminished weld distortion, and improved weld quality, which will decrease costs and improve cycle times.

The NCEMT is also evaluating Hull Treatment (HT) for DD(X). The objective is to reduce installation, sustainment, and decommissioning costs for HT by finding less cumbersome application materials and processes that meet performance and service-life expectations. If the development of an advanced application treatment is successful, it could reduce HT installation and procurement costs by 50 percent.

Rapid Response Projects Showcase NCEMT Adaptability

Rapid Response projects—quick turnaround initiatives to insert technology to meet an immediate fleet need—reflect the NCEMT's agility and adaptability. One such project evaluated the effectiveness of laser peening to increase fatigue resistance of a high-strength steel shaft used on one of the Naval Sea Systems Command's (NAVSEA) critical weapon systems. The NCEMT determined that laser peening improved stress-controlled fatigue life by factors ranging from 3 to 13 depending on stress levels.

The process improvements developed through another Rapid Response project will be used to support future production of saddle castings for the Virginia-Class submarine. The NCEMT worked with Northrop Grumman Newport News, General Dynamics Electric Boat, Tech Cast, Inc., and the Naval Surface Warfare Center-Carderock Division (NSWCCD) to develop and verify an improved stainless steel investment casting process that reduced the component porosity defect rate from 80 percent to 0 percent and enhanced the Charpy V-notch impact energy by 100 percent.

Stakeholder-Sponored Efforts Benefit Navy

Two projects are underway to support the U.S. Navy. With NAVSEA and the NSWCCD, the NCEMT is conducting Research, Development, Testing, and Evaluation required for certification of new naval shipbuilding materials and technologies designed to increase the implementation of metallic materials for naval ships and components. A Navy metallic materials database is also being developed to provide a convenient, comprehensive pool of knowledge that will help enhance the use of metallic materials that can improve performance and affordability throughout the shipbuilding community.

The NCEMT led an IPT that developed high-strength marine-grade fasteners that will be used on Virginia-Class submarines and other weapon systems.

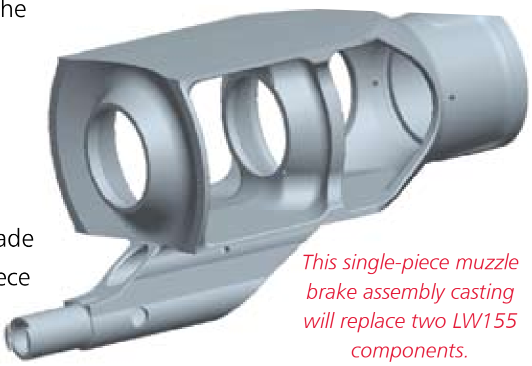
The NCEMT is also working with Spiritech to design a prototype mobile waterjet system that eliminates fire hazards, noxious fumes, and metallurgical damage and distortion that occurs with conventional cutting methods.

Satisfying client needs and implementing better solutions remain critical focuses as we extend the world's knowledge and application of advanced metalworking technology.

To help keep U.S. warfighters combat ready at a moment's notice, the NCEMT and its industry partners identify and optimize new technologies with the potential to enhance survivability, agility, and maintainability, making the best weapon systems even better.

Ground Weapon Systems

One titanium-intensive weapon system in particular has been a key focus of NCEMT activity. The Marine Corps' M777 Lightweight 155mm Howitzer (LW155) was designed to improve ground and air mobility for quick battlefield response. Using titanium alloys in place of steel substantially reduces the weight of each gun, resulting in enhanced transport and reduced setup time. Advanced metalworking approaches are being applied to improve the manufacture of the LW155.



This single-piece muzzle brake assembly casting will replace two LW155 components.

Among these projects is an initiative to improve the affordability of titanium components while reducing welding lineage and parts count. The LW155 spade component was converted from a 60-piece fabricated and welded component into a single-piece investment casting. The implementation of this component into the production of the first LW155 will provide cost savings of $27 million. Similar work by the NCEMT has resulted in additional savings totaling about $46 million.

The NCEMT is a member of a team that is facilitating the integration of an active suspension system into the Lancer combat demonstrator.

In addition, a single-piece steel investment casting is being developed to replace two existing LW155 components: the muzzle brake and the tow-eye bracket. Following production of a series of prototype castings by the contractor, the NCEMT will confirm dimensional requirements and conduct material property evaluations to ensure the component will withstand the challenges of field operations.

Advanced Metalworking Benefits Next-Generation Weapon Systems

The NCEMT is a member of a team that is facilitating the integration of an active suspension system into another Future Combat Systems demonstrator, the Lancer Combat Vehicle. The NCEMT is working with U.S. Army's Tank Automotive Research, Development and Engineering Center (TARDEC), United Defense LP (now part of BAE Systems), University of Texas Center for Electromechanics, and L3 Communications Electronic Systems, Inc. (formerly known as Northrop Grumman Canada). The team facilitated the design, manufacture, and implementation of the active suspension system on the Lancer demonstrator vehicle.

Developing Promising Technologies for Diverse Projects

The U.S. Army's next-generation ground combat vehicles and combat service support systems demand improved structural and ballistic performance at a reduced weight to meet Future Combat Systems vehicle goals. The NCEMT has long been involved in the implementation of advanced materials and manufacturing technologies to help accomplish these goals. In this work, the NCEMT is working closely with TARDEC and combat vehicle program managers and manufacturers to transition advanced lightweight materials, novel designs, and innovative processing technologies developed under the Combat Vehicle Research Project and other TARDEC Combat Vehicle programs. Among the projects currently underway:

The NCEMT is designing and fabricating the top plate—which includes ring-rolled forgings—for the Future Combat Systems' Non-Line-of-Site Cannon.

Combat vehicle project activity led to the design and development of a replacement for the medium-weight Future Tactical Truck Systems Trailer. A weight-efficient design enabled by friction stir welding (FSW) was produced using high-strength aluminum lithium alloy 2195 T8P4 extrusions and plate.

Using FSW, the NCEMT worked with combat vehicle prime contractors to co-design and construct several weight-efficient mine blast and ballistic test articles.

These and other structures are being evaluated to rapidly effect technology transition, meeting the deployment requirements of today's and future ground vehicle systems.

The NCEMT is helping to develop innovative manufacturing approaches for the Future Combat Systems (FCS) Non-Line-Of-Site Cannon.

The NCEMT's portfolio includes advanced metalworking projects that benefit military aircraft. Two projects representative of the NCEMT's work are highlighted in this section. The first involves a planned unmanned aircraft, and the second, one of the military's most widely used helicopters, the Sikorsky H-60 Seahawk.

Aircraft

A new project, the Joint-Unmanned Combat Air System (J-UCAS) Metallic Manufacturing Technology Transition Program, seeks to achieve both cost and weight reductions in the J-UCAS Wing Outboard Fuselage (WOF) and other airframe components. Advanced high-speed machining is being utilized to manufacture ultra-thin aluminum spars. Direct Deposit technology is the choice to produce lower-cost titanium components. The NCEMT, working with the DARPA/J-UCAS Joint Program Office, will establish requirements and develop component designs and metal processing technologies. Ultimately, a full-scale WOF will be built and tested to demonstrate the applicability of the new metalworking technologies. These advanced manufacturing technologies could result in a cost avoidance of $170 million. This project is being coordinated with a Systems Design and Manufacturing Development effort already initiated by the Composites Manufacturing Technology Center.

Improving Service Life of Aircraft Components

A second project is evaluating methods of improving the service life of the Sikorsky Aircraft Corporation (SAC) H-60 Seahawk helicopter's dynamic components. The NCEMT is working with a project team that includes NAVAIRSYSCOM and SAC.

Due to increased gross weights and changes in mission profiles and usage, MH-60(R/S) dynamic component fatigue lives are dramatically lower than those of the legacy SH-60B. These low fatigue lives increase costs and force more frequent parts replacement.

The NCEMT has assisted the team by focusing on corrosion, wear, maintenance damage, and review of aircraft maintenance processes and procedures. In addition, the team is submitting recommendations to improve the manufacturing, maintenance, installation/removal, and interchangeability between aircraft of the MH-60R Sonobuoy Launcher assembly.

The Dynamic Components team has already outlined many recommendations for dynamic component service life improvements. Some of the most promising and cost effective involve refining the design of tools that will prevent damage to the main support bridge and adjacent components during maintenance; documenting improvements to the MH-60R maintenance process and procedures for dynamic components; and applying alternate sealants and coatings to prevent or reduce corrosion. The NCEMT consistently provides reliable, cost effective recommendations that meet today's ever-increasing metalworking technology challenges.

The primary goal of the NCEMT is the development and implementation of advanced metalworking technologies for military applications. The three technologies highlighted in this section are being used on projects featured in this report, and play a critical role in reducing costs and improving the performance of weapon systems.

Advanced Metalworking Technologies: Optimizing Cost, Performance and Manufacturability

Flowformed Components are Precise, Economical, and Flexible

Flowforming is a cold forming process that creates seamless, dimensionally precise, hollow cylinders (or other shapes with a rotational axis of symmetry). Because of the high degree of accuracy achieved from flowforming, it has become widely accepted for the production of tube-like components for aerospace and military applications. The NCEMT and its industry partners have made strides in further advancing the world's knowledge and use of this metal-forming process.

Background

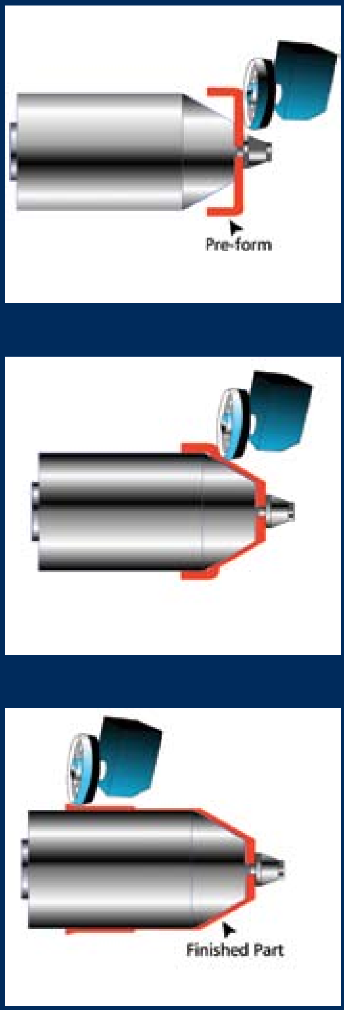
During flowforming, compressive force is applied to the outside of a cylindrical component called a pre-form, which is attached to a rotating mandrel. A combination of axial and radial forces from two or more computer-controlled rollers, which are evenly spaced around the pre-form, shape the material and reduce wall thickness.

The quality and design of the pre-form is key to successful flowforming. The pre-form must be engineered to ensure that the appropriate amount of material forms into the final shape; the accuracy and finish of the final shape directly reflects the precision of the pre-form. Pre-forms, which are created using deep drawing, stamping, press forming, or any number of other processes, can be made from a variety of metals, including titanium, aluminum, steel, and superalloys. The NCEMT has conducted most project work on high-strength, corrosion-resistant titanium alloys.

There are three methods of flowforming. Forward flowforming is used when the component being made has one closed or semi-closed end, such as a cylinder. Clamped by hydraulic force, the bottom of the pre-form rests against and rotates with the mandrel. As rollers are fed from right to left, the flowformed material moves in the same direction.

Reverse flowforming is used for components that have two open ends, such as tubes. The pre-form is placed over the mandrel and pushed to the end against a serrated drive ring. The axial thrust of the rollers forces the pre-form against the drive ring. The longitudinal feed moves from right to left; however, the flowformed metal moves in the opposite direction of the rollers.

Flowforming Process



The process (top to bottom) begins with a pre-form attached to a rotating mandrel. Diagram shows roller applying compressive force to the pre-form, creating the finished shape.

Shearforming, the third flowforming method, is used to form conical, radial, or parabolic geometries. Generally, the pre-forms are shaped like circular discs. With the pre-form held firmly against the nose of the mandrel by hydraulic force from the tailstock or other means, the carriage moves from right to left. The rollers plastically deform, or "shear," and flow the available metal against the mandrel.

Benefits

Flowforming is an innovative, cost-effective solution for creating complex, hollow metal components and is a viable alternative to traditional machining and deep drawing. The flowforming process generates seamless components with a superior finish and increased metallurgical strength and hardness. Its flexibility allows for design versatility and tolerance control as well as variable wall thickness with increased tensile strength, accuracy, and refined grain structure. Flowforming can result in improved physical properties and improved response to heat treatment due to the refined grain structure.

Cost savings is an essential consideration when discussing the benefits of flowforming. For instance, this metalworking process can reduce the number of parts necessary to perform a particular function, thereby reducing assembly costs and decreasing the number of component parts that must be outsourced or kept in inventory. Flowforming also can reduce or eliminate welding, finishing, and testing costs and ultimately may require less material than other manufacturing processes.

Applications

The NCEMT has worked with leading partners in the United States, including Dynamic Machine Works and Precision Metal Forming Industries, to evaluate flowforming for the cradle tubes on the M777 Lightweight Howitzer. The demonstrations resulted in a Ti-6Al-4V seamless tube that meets all dimensional and mechanical property requirements for the program.

Another project has enabled the production of affordable, flowformed, five-inch cartridge casings that reduce life-cycle expenses and improve the performance of U.S. Navy five-inch guns. Traditionally, the steel cartridge cases had been manufactured using a deep-drawing process that is no longer cost effective. In conjunction with the Naval Surface Warfare Center Division at Indian Head, Dynamic Machine Works, and Owego Heat Treat, Inc., the NCEMT identified flowforming processes that worked with a new alloy and new heat treatment to achieve all project objectives.

Future advances in flowforming will occur as new machines are built that have more power, greater stiffness, and better numerical control for path management. In addition, new applications are made possible as numerical process models are developed that allow simulation of material flow behavior and interaction with factors such as machine feed rates, machine speeds, tooling configuration, pre-form shape, and material characteristics.

Friction Stir Welding

Invented in 1991 by Wayne Thomas of The Welding Institute in the United Kingdom, friction stir welding (FSW) is a joining technique that has gained attention as an attractive alternative to traditional fusion welding for many metals, but especially for joining aluminum alloys.

Background

In FSW, metal sheets or plates to be joined are aligned next to each other and clamped in place. A non-consumable cylindrical tool comprised of a profiled probe or "pin" is rotated and plunged into the joint between the plates. The probe nearly penetrates the workpiece. As the tool traverses the weld line, frictional heat from the relative motion between the tool and the workpiece, coupled with heat from

The NCEMT is developing friction stir welding processes for use in U.S. Navy and Army applications.

the tool shoulder rubbing on the top surfaces of the plates to be joined, softens the workpieces so their material can be stirred by the probe. Because the material displays no discernible melting, the resulting bond is made in the solid state, thereby avoiding many of the problems associated with traditional fusion welding such as segregation, severe residual stresses, distortion, and evaporation of volatile elements.

Benefits

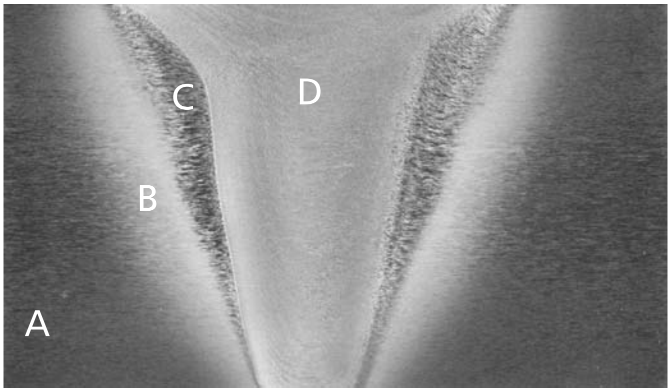
FSW's ability to create a solid state bond makes it a prime candidate for materials that are difficult to join using traditional arc welding techniques. Aluminum and aluminum alloys, which can be difficult to weld due to their high thermal conductivity, large freezing range, rapid formation of oxide film over the liquid weld puddle, and tendency to form porosity and solidification cracks, were the first materials to be joined using FSW; however, the technology has also been effective on copper, lead, magnesium, titanium, zinc, mild steel, selected stainless steels, and nickel alloys.

FSW significantly reduces residual stresses compared to traditional welding techniques and creates strong and ductile joints with low distortion, shrinkage and porosity. The FSW process is relatively simple, is fully mechanized and can function well in any position (gravity has no effect on the FSW process, as opposed to fusion welding). In addition, FSW consumes less energy than fusion welding and eliminates the need for filler wire, thereby making FSW a more environmentally friendly technique.

Characterization of Friction Stir Welds

Although tool design, speed of rotation and the material being joined can change the microstructure of a friction stir weld, most welds can be characterized using four distinct zones as shown above. In the "Unaffected Zone" (A), material may experience a thermal cycle from the weld, but is unaffected in terms of structure or material properties. Closer to the weld in the "Heat Affected Zone" (B), the material experiences changes in microstructure and material properties from the heat of welding, but not from deformation. In the "Thermomechanically Affected Zone" (C), the material is affected by the heat and is plastically deformed by the welding process. In this area, the general grain structure of the original material is retained, although in a deformed state. Finally, in the central region of the weld, known as the "Stir Zone" (D), the structure of the material is heavily deformed and refined.

Friction Stir Weld Zones



Friction stir welding affects the welded material's microstructure, resulting in four distinct zones: the Unaffected Zone (A), the Heat Affected Zone (B), the Thermomechanically Affected Zone (C), and the Stir Zone (D).

Applications

Friction stir welding was rapidly adopted as a joining technique for the production of marine structures, especially in Scandinavia where high-speed ferry construction has benefited from the process since the mid-1990s. Application in the United States has been slower, but interest has gradually improved as more manufacturers have learned of the benefits of the process. FSW was used to create aluminum-stiffened panels for the U.S. Navy's FSF-1 "Sea Fighter" high-speed craft, and the process is being considered for ground combat vehicles and other Navy applications, including construction of bulkheads, superstructure, and decks.

The NCEMT, under TARDEC sponsorship, has installed a three-story tall FSW system capable of fabricating a full-size combat vehicle. The system is able to create welds in two-inch thick aluminum plates in a single pass. The NCEMT has been using the system to develop the process for Navy applications, and to fabricate concept trailers and Future Combat Systems combat vehicle test articles for the U.S. Army.

The increasing attention on FSW has already resulted in many variations of the welding process, each with its own benefits. The creation of additional process variants, the development of new welding tool designs, and the identification of best practices are likely to make FSW even more versatile and effective in the future. As these new methods are developed, new applications are constantly being identified and developed, making FSW an area of intense interest.

Aerospace Materials Find a Niche on the Ground

Background

The aerospace industry has long required specialized materials to meet strict quality and safety requirements. To address these requirements, materials certified for aerospace use typically exhibit high strength-to-weight ratios, superior fatigue strength and enhanced resistance to corrosion. In addition, the materials must be free of defects that could potentially cause failure of key components or systems mid-air.

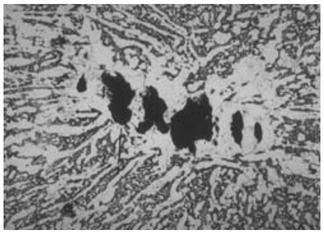
Due to the high cost of manufacturing materials with these properties, past demand for them was usually limited to and dependent on the aerospace industry. While many of these materials may have been appropriate for non-aerospace applications such as military ground vehicles, the prohibitive cost and lack of designer experience with them impeded implementation.

Technology

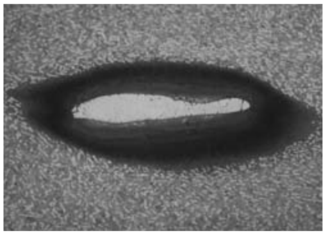
Times are changing. As manufacturing technologies improve and traditional aerospace materials become more affordable, their use outside of the aerospace industry is being promoted.

One of the most critical issues faced by the aerospace industry is the elimination of material defects. Hard alpha and high-density inclusions in titanium are two examples of such defects. These imperfections can reduce fracture toughness, fatigue resistance and ductility, thereby potentially causing catastrophic failures if they find their way into critical systems such as turbine jet engines. The 1989 crash of a DC-10 in Sioux City, Iowa, is one of the most well-known examples of such a failure. According to National Transportation Safety Board report No. NTSB/AAR-90/06, a crack emanating from a hard alpha inclusion in the titanium fan hub in one of the engines caused the component to fail. The resulting shrapnel severed hydraulic lines and ultimately caused the plane to crash during an attempted emergency landing.

Hard-Alpha Inclusion



High-Density Inclusion



Material defects, including hard alpha (left) and high-density (right) inclusions, can alter the effectiveness of aerospace materials.

To prevent such failures, highly controlled hearth melting processes, as well as rigorous testing and inspection, are employed by the aerospace industry to improve material cleanliness. Because military ground vehicles typically do not have the extreme fracture toughness and fatigue requirements that aerospace components do, such defects present less of a problem. As a result, material processing and inspection procedures can be tailored to the less stringent ground vehicle application requirements, thereby making the materials more cost effective to implement.

Two additional aerospace material characteristics that are being considered in the design of military ground vehicles are strength-to-weight ratio and ballistic performance. Faced with the challenge of creating transportable vehicles that provide superior protection at the lowest possible weight, designers are considering aerospace materials such as titanium (Ti) and aluminum-lithium (Al-Li) alloys.

Applications

Titanium, a ubiquitous aerospace material, recently found a home on several ground systems including the Stryker Mobile Gun System and the M777 Lightweight Howitzer. One of the key performance factors of the Stryker vehicle is its need to be transportable by C-130 cargo plane, allowing it to be deployed anywhere in the world within four days. To help reduce the vehicle weight to meet this requirement, Ti is being considered as a replacement for steel on components such as the gun pod and elevation arm.

The M777 is a Ti-intensive design that exploits high-strength alloy Ti-6Al-4V, which enabled the M777 to be approximately 6,000 lbs lighter than its 16,000 lb. steel-intensive predecessor. Work by the NCEMT has enabled large near-net shape Ti-6Al-4V castings to significantly reduce parts count and welding lineage, resulting in a lower cost, more robust weapon system.

Al-Li alloy 2195—the main structural alloy on the External Tank of the Space Shuttle—and its sister alloy 2094 are being transitioned to military ground vehicle applications by the NCEMT. Their high specific strength, stiffness, and damage tolerance have made them effective in reducing weight on aircraft and space launch systems. The weldability, fracture toughness and strong ballistic performance of 2195 landed it the distinction of being the first Al-Li alloy to be seriously considered for use on a military ground vehicle, as evidenced by its use on the United Defense (now BAE Systems) Future Combat System-Wheeled (FCS-W) prototype.

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Nimitz-class aircraft carrier USS Carl Vinson (CVN-70). U.S. Navy photo by Photographer's Mate 3rd Class Matthew M. Todhunter

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USNS Mercy. U.S. Navy photo by Journalist 1st Class Joshua Smith

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Virginia-Class submarine Texas (SSN 775). Photo by Stu Gilman, Northrop Grumman Newport News

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Machined single-piece muzzle brake assembly casting. Courtesy of Joint Program Management Office.

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Future Combat System - Tracked prototype. BAE Systems (formerly United Defense, L.P.)

Non-Line-Of-Site Cannon. Photo courtesy of U.S. Army

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X-47A J-UCAS. Northrop Grumman photo

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Flowformed components process. Courtesy of PMF Industries

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Friction stir welding. Cramer Studio, Inc.

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Material defects. GE Aircraft Engines photo

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Two HH-60H Seahawk helicopters and the Nimitz-class aircraft carrier USS Theodore Roosevelt (CVN-71). U.S. Navy photo by Photographer's Mate Airman Eben Boothby

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F-14 "Tomcat." U.S. Navy photo by Photographer's Mate 3rd Class Todd Frantom

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