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NCEMT Identifies Effective Rhenium Fabrication Processes

Driven by the need to reduce manufacturing costs and excessive lead times that currently affect the deployment of propulsion systems containing rhenium components, such as the Standard Missile 3, the NCEMT has conducted a rhenium fabrication study at the request of the U.S. Navy.

The NCEMT evaluated several processes to establish best machining practices for rhenium. Rhenium was machined under test conditions using production-type equipment and evaluated both within the NCEMT and by independent machine shops. The NCEMT's technical approach was to evaluate traditional machining methods such as wire electrodischarge machining (EDM); sinker EDM; and alternative, innovative approaches. The NCEMT evaluated nonconventional machining processes involving electrochemical machining (ECM), electrochemical grinding (ECG), femtosecond laser cutting, and abrasive waterjet cutting. Several of these have not previously been applied to rhenium, but can now be added to the array of machining options and fulfill niche applications.

Rhenium is the material of choice for many critical applications such as propulsion components. Its unique properties include high-temperature strength and immunity to thermal shock. But, while these properties are highly desirable for some applications, they also make rhenium very difficult to form into complex shapes. Machining is currently accomplished through a combination of EDM and diamond grinding. EDM is a relatively slow process and the supply of machine shops with rhenium experience is scarce. The rhenium study was conceived to find better machining practices. To achieve the Navy's goal, the NCEMT:

- Characterized EDM processes on the basis of microstructural damage, recast layer, microcracking, deformation and surface roughness.
- Conducted beta-site testing to determine if EDM shops with no experience with rhenium would be able to successfully machine metal if given guidelines.
- Examined alternative machining processes to augment EDM and grinding processes, recognizing unique needs of the rhenium community.

The NCEMT's study confirms that EDM is an excellent method to shape rhenium. Any EDM shop can now cut rhenium using standard equipment and materials. Common brass can be used as electrode material for wire EDM and copper-tungsten composite can be used for sinker EDM. For EDM-cut surfaces that will not be removed by subsequent processes such as grinding, the user should be aware of microstructural damage that EDM can cause. Microcracks, deformation twinning, and contamination with electrode materials are not unusual to find at depths up to 50 µm in rhenium using typical EDM. When a multipass wire EDM is fully optimized, damaged layers can be essentially eliminated and contamination levels reduced by 99 percent. The multipass wire EDM process does not automatically guarantee elimination of artifacts, and the need to test, optimize and qualify individual shops has been demonstrated by the beta-site test. Sinker EDM trials call for more tests due to microcracking and deformation twinning.

Standard Missile 3 Launch
Photo courtesy: Raytheon

To remove electrode contamination from a multipass wire EDM process, the NCEMT developed a low-hazard chemical cleaning process. The low levels of residue can now be removed to below detection limits of Energy Dispersive Spectrometry (EDS) (0.1 % by weight) with this process. Single-pass wire and some sinker EDM residues also respond to this technique, but cannot be fully eliminated.

The NCEMT's rhenium fabrication study shows that several alternative processes could be used for specific applications. Both ECM and ECG have demonstrated excellent utility and may prove useful in machining complex production parts. Abrasive waterjet cutting has shown some utility and may allow rough cutting of blanks more quickly than wire EDM. Femtosecond laser has been successful in cutting thin sheets of rhenium and may offer the ability to pierce and cut fine detail in flat sheets and foils. Micro-EDM is effective in sinking micro-scopic holes in rhenium and has already found application in cutting artificial defects into a radiographic penetrometer. ■

NCEMT Contributes to LBVDS Passing Sea Test

The Lead Magnesium Niobate (PMN) Electrostrictive Transduction Material Manufacturing project achieved its project goal by contributing to a successful sea test of the Lightweight Broadband Variable Depth Sonar (LBVDS) system. When the LBVDS Program technical team, consisting of NAVSEA Newport and Lockheed Martin, needed to determine why PMN ceramics were failing in use as acoustic transducers, they requested the NCEMT's assistance in improving the mechanical reliability of the high-power density PMN ceramics used in acoustic transducers. The goal was to improve the ceramics so that the transducers would survive long enough to pass a sea test.

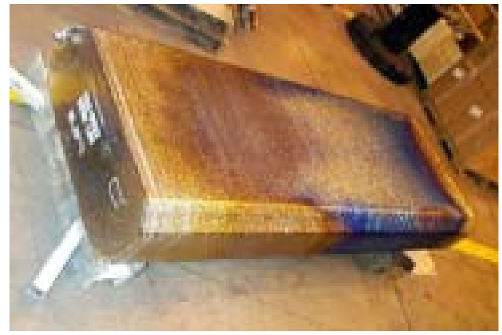
The NCEMT used its experience with mechanical testing, metallography, and fracture analysis to determine baseline mechanical properties and flaw populations for PMN ceramic plates used in transducers. From the beginning, the NCEMT and PMN manufacturers Lockheed Martin, EDO Corporation, and TRS Ceramics worked as a team to apply information gained from fracture analysis to successfully improve ceramic processing. The NCEMT worked with NAVSEA Newport to implement a method for acoustic emission monitoring of compression testing, which allowed measurement of onset of failure. NCEMT mechanical property data was used by the LBVDS team to improve its models that predict transducer failure.

Another critical need that was identified was an effective screening test for discriminating between good and bad ceramic plates. The NCEMT worked with Lockheed Martin to develop electromechanical testing techniques to improve screening procedures and increase understanding of failure.

In the end, the LBVDS sea test on a research vessel demonstrated that the system could broadcast a broadband signal in the ocean and achieve the desired detection range, meeting program goals. The NCEMT's effort contributed to understanding the failure mechanisms and failure envelope of PMN, which is critical to getting PMN accepted and the LBVDS system tested at sea. The successful sea test was truly a team effort. ■

NCEMT Teams with RMI Titanium and the U.S. Army to Develop Low-Cost Titanium Alloy Ingots

The NCEMT, RMI Titanium, and the U.S. Army are teaming up to develop a plasma arc cold hearth melting (PAM) process to melt and cast titanium alloy (Ti-6Al-4V) into high-quality rectangular slabs that are suitable for rolling directly into armor plate and other applications. This advanced PAM process will result in cost savings of up to 25 percent over current casting processes. With these reduced costs, titanium can be used in increased quantities in military vehicles and armament to reduce their weight and enhance their deployment and performance.



Titanium Slab
This slab was melted and cast by the plasma arc cold hearth melting process.

Titanium used for armor plate and similar applications does not require the degree of processing as does titanium used for more stringent applications such as rotating parts in aerospace. In the conventional refinement process, aerospace-quality titanium is typically melted several times under vacuum or a protective inert atmosphere and subsequently cast into circular ingots. Casting single-melt titanium into rectangular molds enables it to be rolled directly into plate, increasing the material yield, improving its mechanical properties, and reducing its cost. However, commercial attempts to cast titanium into rectangular slabs by the PAM process have missed the mark. These attempts, to date, have resulted in poor ingot surface quality and subsequently poor plate quality.

In contrast, titanium slabs have been successfully cast by the PAM process in this project. Four 13" x 34" x 50" titanium slabs were melted with different combinations of torch power, height and patterns, and casting rates. The casting of the titanium slabs was done sequentially using modeling refinements developed by the NCEMT, as a guide to improving surface quality. All four slabs were cast successfully. The first two slabs were rolled into 1" armor plate for use in the Integrated Hybrid Vehicle, and 5mm plate for use in the Lightweight 155mm Howitzer. A fifth slab will be cast to 125" in length with the same cross section as the first four slabs. The remaining slabs will be rolled into a series of thicknesses for use in a variety of military equipment in which weight is a key factor. A series of experiments is being conducted to establish the ballistics and the envelope of performance of the PAM material.

Lightweight 155mm Howitzer
The NCEMT developed modeling refinements to cost-effectively cast titanium slabs for use in armament.

As compared to the double-melting process of round ingots, the advanced PAM technology yields cost savings of approximately 25 percent, which will significantly increase titanium usage in military vehicles, decreasing their weight, facilitating their deployment and increasing their performance.

RMI Titanium, as a key industrial partner in this project, is currently producing slabs for evaluation by the United Defense Limited Partnership and General Dynamics Land Systems and intends to ultimately develop a new market in this area. ■

Materials Selection for Light, Strong Performance and Cost-Effective Design

(This is Part 2 of 2. Part 1 appeared in the Winter 2002 issue.)

Part 1 discussed how the NCEMT helps clients to identify materials that fulfill their design requirements for being light, strong, stiff, high-vibration, damage-tolerant, corrosion-resistant, and cost-effective. Part 2 will discuss the development of performance indices and examples of material selection for light and strong fracture toughness-resistance and cost-effective materials.

Performance indices allow for ranking of potential candidate materials and optimization of the desired material properties. According to M.F. Ashby ["Materials Selection and Design," *ASM Handbook*, Vol. 20, pp. 32–64.], a performance index is a group of material properties that govern some aspect of the performance of a component. The index is derived based upon design objectives such as specific property (property/density), strength, modulus, fatigue, cost, etc. The performance on most mechanical systems is limited not by a single property, but by a combination of them.

Crusader Objective Track
The NCEMT Team identified possible alloys to be used in track systems.

Performance indices are represented as M= σ_y/d or M= E/d, where σ_y is yield strength, E is the Young's modulus, d is the density of the material. The lightest materials that will carry the load, without failing, are those made from a material with the largest value of σ_y/d. Similarly, the stiffest materials that will carry the load are those made from the largest value of E/d. If minimizing cost is also the goal, then the performance index is M= σ_y/d*C or M=E/d*C where C is the cost per unit mass.

The following development is due to Ashby, supporting that material for a solid cylindrical tie-rod should be of minimum mass. Assume L is length, P is tensile load, and S is safety factor. Mass (m) is given by: m= A*L*d [Eq.1], where A is the cross-sectional area and d is density of the material. The design requires that L and P are specified and cannot be changed (i.e., they are constraints). However, the radius of the bar is a free variable, as the bar supports the load P. P/A=sy/S [Eq.2], where σ_y is the yield strength. Eliminating A between these two equations results in:
m= (S*P) *(L)*(d/σ_y) or
m= (S*P)*(L)*1/(σ_y/d) [Eq 3].

Equation 3 shows the first term in brackets, F= (S*P), which is the functional requirement. The second term, G=(L), is the geometric parameter. The last bracket, 1/(σ_y/d), is the material performance index. For this case of a bar in tension, the performance index M is given by M= σ_y/d.

Other part geometries and types of loading result in different performance indices. For buckling of a slender column, $E^{1/2}$/d applies, and for the bending of a plate, $E^{1/3}$/d applies. According to Ashby, if these index lines are put on a plot of E versus σ_y, those materials above the lines are better and those below the lines are worse.

The general performance is described by p=f1 (F) * f2 (G) * f3 (M) [Eq. 4], where p describes some aspect of the performance of the components, mass, volume, cost, or life expectancy; and f1, f2, f3 are functions.

Optimum design occurs by selecting the right material and geometry that maximizes or minimizes p according to its desirability or otherwise. The groups in Eq. 4 are separate, then the optimum choice of material becomes independent of the details of the design. It is the same for all geometries, G, and all values of the functional requirements, F. Then, the optimum subset of materials can be identified without solving the complete design problem or even knowing all details of F and G. This enables enormous simplification. Maximizing (M), which was defined earlier as performance index, maximizes the performance for all F and G. Examples are given below for light, strong fracture toughness resistance and cost-effective design (Figures 1 and 2). ■

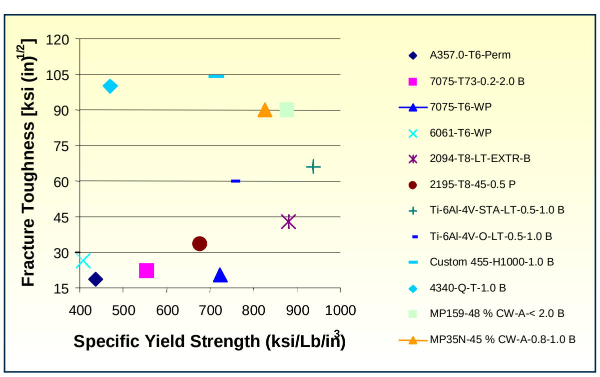


Figure 1. Fracture toughness versus specific yield strength of selected alloys
The lightest, high-strength and high-fracture toughness alloys are on the right top side of the figure for the load dominated design.

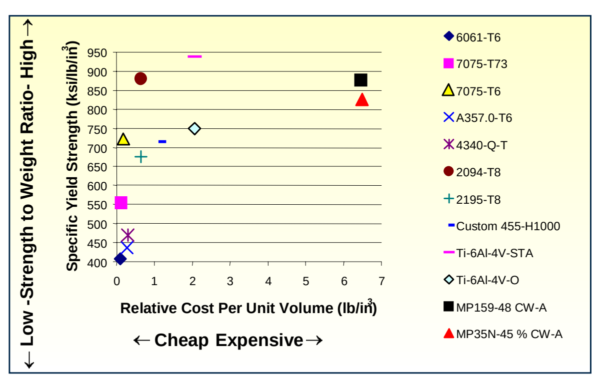


Figure 2. Specific yield strength versus relative cost per unit of selected alloys
The aluminum alloy 6061 is taken as base. The higher the specific yield strength of the alloy the higher the cost compared to AA6061 alloy.

Program News/Events

NCEMT is Second COE to Visit NAVSEA

Mr. Gregg Hagedorn, SEA 05B, Executive Director; Rear Admiral Paul Sullivan, SEA 05 Deputy Commander; Mr. Greg Woods, SEA 05RI, MANTECH Program Office; and Mr. Francois Mollard, National Center for Excellence in Metalworking Technology (*CTC*/NCEMT)

On February 13, 2002, NCEMT representatives were hosted by the MANTECH Program Office of the Naval Sea Systems Command (NAVSEA) at its new location at the Washington Navy Yard. This visit was part of a NAVSEA effort to facilitate communications between the NAVSEA Program Offices and the various Centers of Excellence (COEs) set up by the Navy MANTECH Program Office. A specific focus was to review ongoing projects and to identify new acquisition and sustainment issues that the COEs could be instrumental in solving. The NCEMT was the second Navy COE, after the Navy Joining Center, to visit the Command. Other Centers visited at various times through mid-May.

The NCEMT visit was arranged by Greg Woods, SEA 05R1, NAVSEA MANTECH Program Office. Richard J. Henry, NCEMT Program Director, gave a comprehensive briefing on the NCEMT Operations, emphasizing recently completed and ongoing projects that support NAVSEA objectives. The NAVSEA Program Offices that were represented at the meeting included Aircraft Carriers, Expeditionary Warfare, Mine and Undersea Warfare, Submarines, and Theatre Surface Combatants. A display booth, featuring NCEMT projects and accomplishments, had also been set up in the NAVSEA Atrium lobby, where Gerard (Jeff) Mercier and Francois Mollard (*CTC*/NCEMT) were available to greet visitors and answer their questions. The numerous NAVSEA visitors to the booth included Rear Admiral Paul Sullivan, SEA 05 Deputy Commander, and Gregg Hagedorn, SEA 05B Executive Director, a clear indication of the level of interest and support by NAVSEA for the Navy MANTECH program in general and for the NCEMT in particular. ■

NCEMT Co-Organized Highly Successful First Workshop on Friction Stir Welding Technology for Defense Applications

About 75 persons attended this first workshop focused on Friction Stir Welding (FSW) Technology for Defense Applications, May 14–15, 2002, in Columbus, Ohio. This (ITAR-restricted) workshop, organized jointly by the NCEMT and the Navy Joining Center (NJC), was hosted by the Edison Welding Institute (EWI). The Navy MANTECH Program of the Office of Naval Research sponsored this event.

Welcoming remarks were given by Ted Ford, President and EWI CEO; Harvey Castner, NJC Director; and Richard J. Henry, NCEMT Program Director. The perspective for FSW in each respective weapons system was presented by Jamie Florence, U.S. Army Tank, Armaments and Automotive Command; Kumar Jata, Air Force Research Laboratory; and Johnnie DeLoach, Naval Surface Warfare Center-Carderock Division.

Fourteen technical presentations by respected experts covered the current and/or planned applications of FSW to systems as diverse as the Marine Corps Advanced Amphibious Assault Vehicle, the C-17 and C-130 cargo planes, and the Space Shuttle. Advances in applying FSW to armor-grade steel, stainless steel, superalloys, and titanium, as well as aluminum alloys, were also described. Technology demonstrations relevant to FSW were given by the staff of EWI. Issues related to process qualification and equipment selection were also discussed.

The workshop concluded with the compilation of a roadmap for future FSW development, led by Walter Roy, Army Research Office and chairperson of the DoD MANTECH Subpanel for Metals Processing and Manufacturing.

The next workshop is scheduled for October 14–15, 2003, in Johnstown, Pennsylvania. It will be hosted by Concurrent Technologies Corporation (*CTC*) and again co-organized by NJC and the NCEMT. ■

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Concurrent Technologies Corporation (*CTC*) operates the National Center for Excellence in Metalworking Technology (NCEMT) for the U.S. Navy Manufacturing Technology (MANTECH) Program. The NCEMT serves as a national resource for developing and disseminating advanced technologies for metalworking products and processes. The NCEMT applies these technologies to solve productivity problems in support of the Navy and Department of Defense needs.

CTC is committed to assisting industry and government achieve world-class competitiveness. Through a unique concurrent engineering framework, *CTC* provides comprehensive solutions that improve our clients' product quality, productivity, and cost effectiveness. The professional staff of *CTC* has the requisite experience, knowledge, and resources to rapidly and effectively meet the diverse needs of our clients by transitioning appropriate science, technology, and management applications.

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