CASE STUDY

FLOWFORMING MORTAR CANNON BARRELS

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Flowformed nickel-base alloy mortar barrels have been fabricated in a program jointly funded by the U.S. Army's Armament Research Development and Engineering Center (ARDEC) headquartered at Picatinny Arsenal, N.J., and the U.S. Marine Corps, Office of Naval Research, Arlington, Va. The goal of the joint program was to demonstrate that lightweight flowformed mortar barrel tubes could be quickly produced, at a cost 50% to 75% less than existing steel barrels, and with lower weight.

Two years after the project was approved, prototype flowformed cannon barrels were successfully fatigue-tested and live-fire tested (Fig. 1) at the Yuma Proving Grounds in Arizona, and more Army personnel were added to the development program.

Steel mortar systems

Today, the United States Armed Forces operate three different types of mortar systems.

- The 60 mm M224 has a range of up to 3490 meters (about two miles).
- The 81 mm M252 is the preferred system for long-range, indirect fire.
- The 120 mm M120/M121 is used for close and continuous fire.

Each of these mortar systems is comprised of four sections: the cannon or gun tube, bipod, baseplate, and sight unit.

The 60 mm and 81 mm mortar cannon barrels are carried, but the 120-mm barrels are vehicle transported. For this reason, it was decided to first focus re-engineering efforts on reducing the weight of the 60 mm and 81 mm barrels.

Today, these two mortar barrels are made via conventional manufacturing processes that include machining solid steel forgings into a thick-wall cannon tube. After that, many hours of machining are required to remove steel on both the inner and outer diameters before the mortar tubes are machined to net shape.

The incumbent steel has been used for mortar tubes for decades. This steel has excellent fatigue characteristics, but its strength wanes at elevated temperatures. Consequently, thick walls have always been required on steel mortar cannon tubes because, under heavy fire, the mortar tube can reach maximum temperatures of 1100°F, and the steel's strength is significantly reduced.

Erosion of the steel tubes has also been a problem. Each time a round is fired, the wall thickness is scrubbed off on a micro-level. Eventually, the wall thickness is worn so thin that the cannon tube is condemned and pulled from the battlefield. In spite of great progress in both manufacturing technologies and advanced materials over the past century, these steel cannon tubes had not changed much.

Fig. 1 — The flowformed mortar tube was live-fire tested at the Yuma Proving Grounds in Arizona by U.S. Army personnel.

Lightweight tube development

Finite element analysis (FEA) computer modeling was used to numerically simulate the dynamic firing conditions in which the mortar cannon tubes function during worst-case scenarios. From there, the design began to be optimized by taking weight out of the tubes. This was done by reducing the wall thickness and by utilizing advanced materials that are very strong and light and retain their strength at 1100°F.

- **Titanium:** Initially, prototype flowformed mortar tubes were made from an alpha-beta titanium alloy. The advantage to the titanium alloy was that it offered a great strength-to-weight ratio, reducing the barrel weight by almost 75% compared to the existing steel barrel. However, like steel, titanium's strength also drops off at 1100°F, not offering great weight advantages. Additionally, it was believed that the steel mortar rounds would score or gall the inner diameter of the titanium tubes when the material became hot under firing conditions.
- **Nickel-base superalloys:** Nickel-base superalloys that serve as shaft and turbine blade materials in hot zones of jet aircraft engines were then tried. Although twice the density of titanium, they retain their strength at the higher operating tem-

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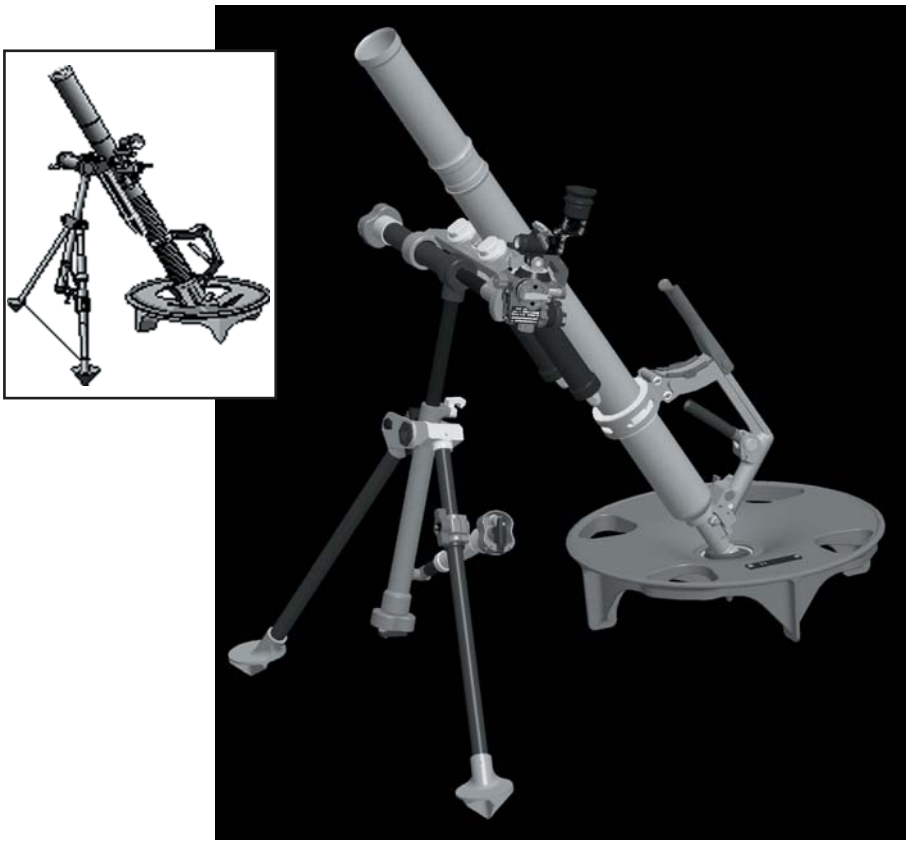

Fig. 2 — The total weight of the 60-mm mortar was reduced from 44 to 32.5 pounds by replacing steel (inset) with flowformed nickel-base alloy 718. This weight savings is a combination of lighter flowformed cannon tube, bipod, and base plate.

peratures, and provide high resistance to corrosion and wear.

The team decided to try alloy 718 per Aerospace Material Specification 5662 (AMS 5662). The ability for this material to retain its strength during temperature changes from 30 to 1200°F is critical to reducing wall thickness of the mortar barrel.

After test firing the nickel mortar tubes in excess of 5000 shots, the wall thickness remained essentially the same, and was not thinned from the shot wear. Therefore, nickel mortar tubes would not be pulled from the field because of wear; instead, the life-limiting factor would be its fatigue life.

To evaluate fatigue life, the flowformed alloy 718 tubes were fatigue tested at Benet Labs, located at Watervliet Arsenal near Albany, New York. Both the 60 mm and 81 mm flowformed, nickel, thin-wall mortar tubes passed the minimum acceptance criteria of 30,000 fatigue cycles, and went on to pass the maximum fatigue criteria of 75,000 fatigue test cycles.

Because the weight of the cannon barrels was reduced, engineers were also able to reduce the weight of the bipod and base plate. The combined weight reduction for the three major components for both mortar systems are significant to the soldiers and Marines carrying them. As shown in Fig. 2, the weight of the steel 60 mm mortar is reduced from 44 to 32.5 pounds.

In October 2007, the U.S. Marine Corps and the U.S. Army's Product Manager for Mortar Systems named Dynamic Flowform Corp. "Small Contractor of the Year 2007." The award was given in recognition of Dynamic's "outstanding efforts to develop lightweight 60 mm and 81 mm flowformed cannon barrels." In January, 2008, the Marine Corps Systems Command in Quantico, Va., awarded a firm-fixed-price contract to Dynamic Flowform Corp. to produce the 60 mm Lightweight Company Mortar System and 81 mm Lightweight Mortar System cannon assemblies and spare components.

Flowforming process

Flowforming is a chipless, cold-metal forming process for net shape or near net shape seamless, thin wall, tubular hardware. Flowforming often creates dimensionally precise diameters and concentric wall thickness, and forms parts that are very straight and round. This either eliminates or substantially reduces the need for expensive post-forming machining operations, saving material and minimizing manufacturing costs.

After a cylindrical workpiece is fitted over a rotating mandrel, hydraulic force is applied to the outside diameter by a set of three CNC-controlled rollers. The correct geometry is achieved when the preform is compressed above its yield strength and plastically deformed.

As the preform wall thickness is reduced by the set of three rollers, the material is lengthened and formed over the rotating mandrel. The process is carried out at room temperature, but due to the large wall deformations, adiabatic heat is generated. Refrigerated coolant floods the workpiece to dissipate the heat.

This cold forming process causes the material's strength to increase, often a beneficial condition. The dimensional accuracies that are consistently achieved are well beyond accuracies possible through hot-forming processes. Additionally, the large deformations during flowforming wall reductions of the material refine the microstructure, thus improving fatigue life. In the context of a mortar barrel, which is a highly pressurized vessel that is fatigue-cycled with every shot, having a fine and uniform microstructure is a significant enhancement to the material's characteristics. ⬣

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Resources:

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