More Bang for the Buck
A *New Design* and *Manufacturing Method* for Deep Penetrating Bomb Cases

The ~4,450-pound BLU-122 deep penetrating bomb was developed by the U.S. Air Force in 2003, making improvements on the BLU-113 penetrator which would enable it to have significant penetration through hard targets. The weapon incorporates ~780 lb of energetic explosive filling, a higher-strength case made from Eglin steel with an ultimate tensile strength of 245-255 ksi, an impact toughness of 11.5-15.5 ft-lb @ -40°F, and a modified nose shape for increased penetration. Despite the improved case, the BLU-122 possesses only 18-20 feet penetrability in 5.0 ksi strength reinforced concrete.

The U.S. Air Force is moving ahead to get a new 2,000-pound class bunker buster bomb filled with 530 lb of explosive material, built around an improved warhead called the BLU-137, which has a steel case made from the USAF-96 steel. This bomb will ultimately replace existing weapons in this category, which have already been a key part of recent engagements. The BLU-137 is intended to provide improvements in capability and survivability over the BLU-109 bomb. The BLU-109 has a steel case made from 4330 modified steel with an ultimate tensile strength of 245-255 ksi and an impact toughness of 20 ft-lb @ -40°F. The BLU-122, BLU-137, and BLU-109 bombs have monolithic and uniform steel cases.

Recently developed ultra-high-performance concrete (UHPC) made by combining pure powdered quartz with a mixture of metals and nanofibers has a compression strength of up to 30,000 psi compared to traditional concrete (up to 5,000 psi). Despite all advantages, the BLU-122 and the BLU-137 bombs cannot penetrate deep targets made from concrete having more than 5,000 psi compression strength.

For decades, the manufacturing method used to produce cases for deep penetrating bombs has been to forge the bomb bodies from steel ingot and extensively machine on a solid forging, along with additional cutting. The forging, machining and cutting processes are very expensive to manufacture. To reduce cost of the traditional methods of manufacturing, an alternate manufacturing process is required that is less expensive and exhibits the same or higher performance than the traditional methods, while increasing the supplier base and manufacturing technology options.

Description

The well-known Eglin steel[1] is utilized for manufacturing cases for the BLU-122 penetrator. Low alloy steel improves the impact toughness of Eglin steel, but its 245 ksi strength is insufficient to penetrate highly defended tar-

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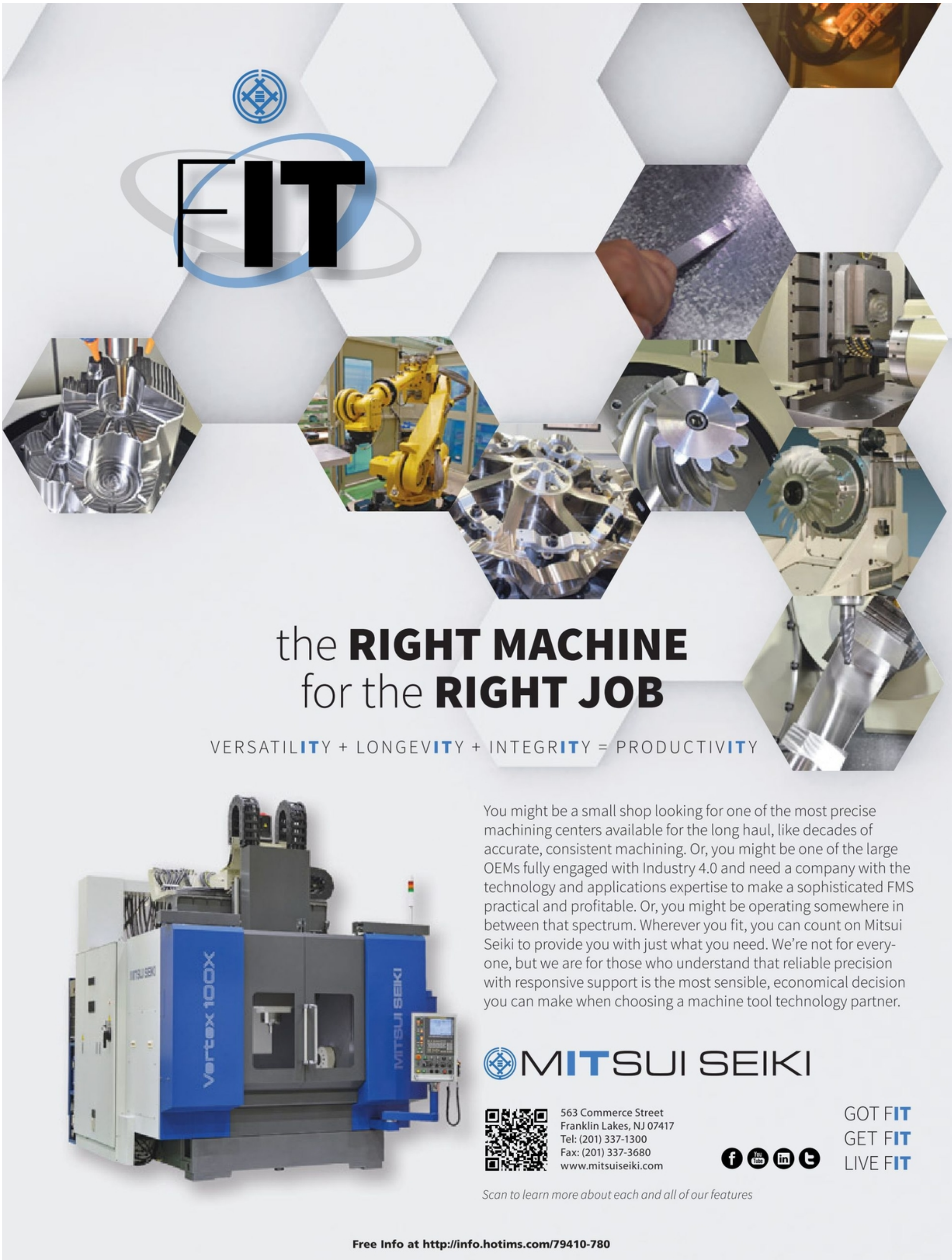
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Steel	HRC	YS ksi	UTS ksi	El %	RA %	CVN, ft-lb	
						@ 70°F	@ -40°F
Military	50-51	195-205	255-265	14-15	48-54	38-42	28-32
Eglin	48-50	195-205	250-260	12-14	44-48	26-32	11.5-15.5
USAF-96	48	187	245	13	-*	-*	30
*unknown							

Typical non-penetrating munitions include aerial laser-guided bombs (top) and the laser-guided Mk 84 GP bomb (bottom). Although effective against surface targets, neither will penetrate reinforced bunkers. (Photo courtesy of author)

gets[2]. A newly developed high-strength steel ("Military-Steel") exhibits superior strength to Eglin steel at the same level of ductility and toughness[3]. Concentrations of expensive elements and the cost of raw materials of Military-Steel are significantly lower than Eglin steel, while the cost of melting, hot forging, and heat treatment are comparable.

The table above shows the typical room temperature quasi-static tensile test results of the air-melted, quenched and low-tempered Military-Steel, Eglin steel, and USAF-96 steel[4], wherein HRC, YS, UTS, El, RA, and CVN are Rockwell hardness scale C, a yield strength at 0.2% offset, an ultimate tensile strength, an elongation at break, a reduction of area, and Charpy v-notch impact toughness energy respectively.

Eglin steel exhibits ~10% increase in yield and tensile strength when strain-rates are increased from quasi-static to 200 s^{-1}, Military-Steel shows approximately the same sensitivity to increasing strain-rates. The tensile and yield strengths of the steels at high strain-rates will be referred to as the dynamic tensile and yield strength.

Military-Steel is superior to the Eglin steel and USAF-96 steel due to:

- Higher hardness and strength at the same ductility and toughness;
- Better formability at hot working;
- Higher hardness and strength at the same ductility and toughness;
- Reduction in total raw material cost by 50% or more through lower concentrations of Mo and elimination of W;
- Better formability at hot working and better machinability.

New designs of the monolithic cases for deep penetrating bombs BLU-122, BLU-109 and its improvement, the BLU-137, have been developed to increase their penetration distances. The new designs are based on the concept that the material and nose of a penetrator play crucial roles in the strength and durability of their cases. If the material of the penetrator does not have enough strength, large deformation of the nose and wall occurs, and as a result, the nose is flattened, and the wall is warped. On the other hand, if the high-strength material of the penetrator does not have enough impact toughness, a fracture of the nose and wall occurs.

Both scenarios lead to a reduction of penetration distance and do not meet the strict requirements for the penetrators. Therefore, the main parameters that affect penetration distance are: strength and toughness of the case material; shape and length of nose; thickness of the wall; length and diameter of the case. The new monolithic cases have the same weight as the standard cases and the same capacities of explosive materials. Projected penetration distance in 5,000 psi (34.5 MPa) strength reinforced concrete of the BLU-122 penetrator with the new monolithic case made from Military-Steel is 40% higher than the penetration distance of the standard case made from Eglin steel[5-6].

Recently developed ultra-high-performance concrete (UHPC) can withstand bombs and bunker penetrators, making it a unique new material that can be utilized for bunkers[7]. UHPC is made by combining pure powdered quartz with a mixture of metals and nanofibers and has compression strength of 30,000 psi (207 MPa) compared to traditional concrete at just 4,000 psi (27.6 MPa).

To reach and destroy well-protected bunkers, new weapon systems such as the 30,000 lb (13,600 kg) Massive Ordnance Penetrator (MOP) and the High Velocity Penetrating Weapons (HVPW) have been designed. However, neither BLU-122 bomb nor MOP or HVPW bombs can penetrate bunkers made from UHPC with compression strength of >10,000 psi (69 MPa) and thickness of >10 ft (3 m). Penetrators with monolithic cases made from materials such as 250-260 ksi (1725-1800 MPa) strength Eglin steel or 280-300 ksi (1930-1970 MPa) strength Military-Steel cannot penetrate bunkers made from UHPC.

To penetrate bunkers made from UHPC, a new composite case has been designed having the following improvements compared to a monolithic case:

- Super-strength materials with strength of >400 ksi (2,750 MPa);
- Nose made from joined super-strength materials with a complex shape;
- Walls made from high-strength and high-impact toughness materials;
- Walls incorporate reinforced components to increase general, and bending, stiffness and reduce dynamic vibration of the walls;
- The nose and walls are joined by a special manufacturing technique;
- Uniform distribution of weight through the length of the case to supply dynamic stability;
- High wear-resistance of the composite case.

The composite case has the same weight and the same capacity for explosive materials as the new monolithic case and the standard case, while the projected cost of production of the composite case is 10-20% higher. The composite case is applicable for the BLU-122, BLU-109, and BLU-137/B penetrators, MOP, and HVPW to pierce bunkers made from UHPC.

An alternate manufacturing process of producing the penetrators and projectiles has been developed to reduce manufacturing cost, improve the manufacturing consistency, and tolerance control.

The method of production includes but is not limited to the following steps:

- Piercing a workpiece to complete the preform stage;
- The hot ring preform is placed on a mandrel in preparation for forging under the press;
- The forging is drawn down and elongates over the mandrel;
- The nose of the case is formed by the closed die forging;
- Planishing to smooth the outside surface.

The proposed technology could be commercially used for fabrication of any metallic axisymmetric items such as variable-diameter tubing and support poles. Other potential applications include aerospace and power generation systems.

Summary

A new monolithic case design for penetrators and projectiles has been developed to increase penetration distance. Projected penetration distance of the BLU-122 penetrator with the new monolithic case made from Military-Steel in 5.0 ksi (34.5 MPa) strength reinforced concrete is 40% higher than the penetration distance of the standard case made from ES-1.

Alternatively, a new design for composite cases of penetrators and projectiles has been developed to penetrate an ultra-high-performance concrete (UHPC). The composite cases provide projected penetrability in UHPC with a compression strength of >20 ksi (138 MPa) and a thickness of >20 ft (6m). The composite cases could be utilized for different types of penetrators, including BLU-122, BLU-109, BLU-137/B, MOP, high velocity HVPW, and projectiles. In addition, an alternate manufacturing process for producing the penetrators and projectiles has been developed to reduce manufacturing cost as well as improve the manufacturing consistency and tolerance control.

This article was written by Dr. Gregory Vartanov, Advanced Materials Development Corp. (Toronto, Canada). For more information, visit ***http://info.hotims.com/79410-503***.

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