ARMAD™

32CrMoV12-10

Next-generation alloy for firearm barrel

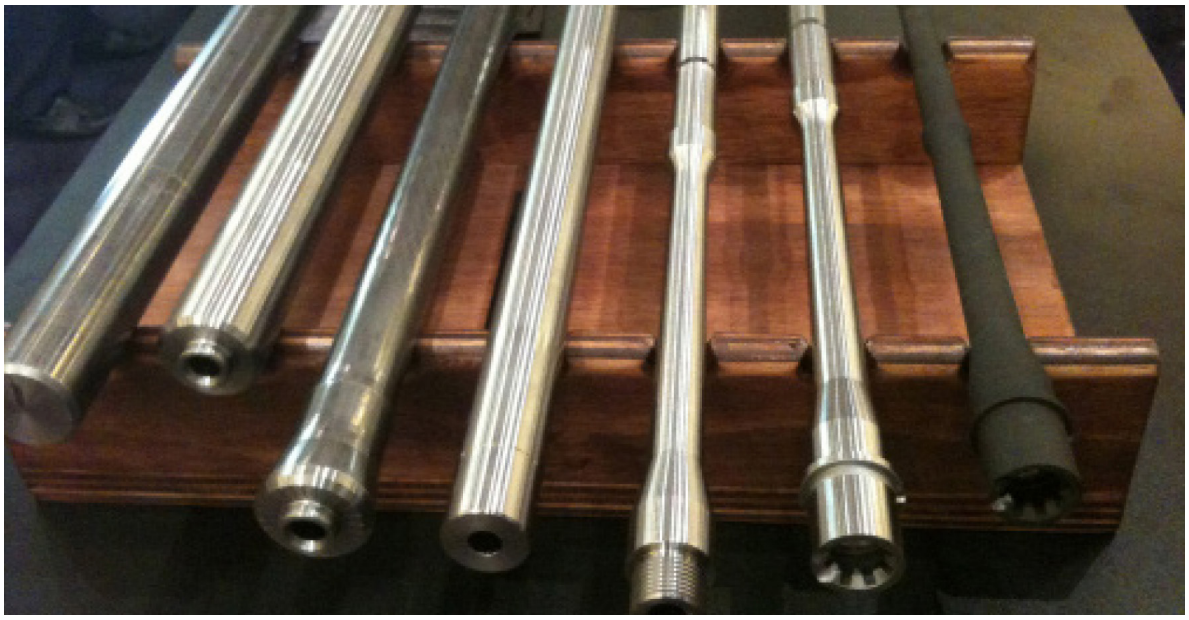
AUBERT&DUVAL

> THE INDUSTRIAL ENVIRONMENT

Aubert & Duval designs cutting-edge metallurgical solutions in the form of parts and long products for the projects of most demanding industries (aerospace, energy, defense, industrial tooling, motor racing, medical,...).

For 70 years, Aubert & Duval has been serving defense industries, mainly by producing:

- Barrel blanks for small, medium and large calibers
- Missile casings
- Critical parts for submarines, military aircraft engines, launchers and satellites.



> ARMAD™ STEEL GRADE DEVELOPMENT

ARMAD™ was developed specifically for small caliber gun barrels.

This high-performance grade offers excellent toughness, thanks to optimized chemical composition and control of the key parameters for melting and processing. This results in higher tensile strength values allowing designers to reduce weight while maintaining safety, even in extreme conditions.

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> APPLICATIONS

Benefits to firearm user:

Increased hardness and higher tempering temperatures improve barrel life because:

- Reduced wear in critical areas of the barrel
- Improved resistance to heat related wear as a result of higher tempering temperature
- Higher strength material allows for reduction in barrel thickness and overall system weight

Higher strength material allows barrel size to be reduced in order to minimize weapon weight.

Military application

Sport shooting

Law enforcement

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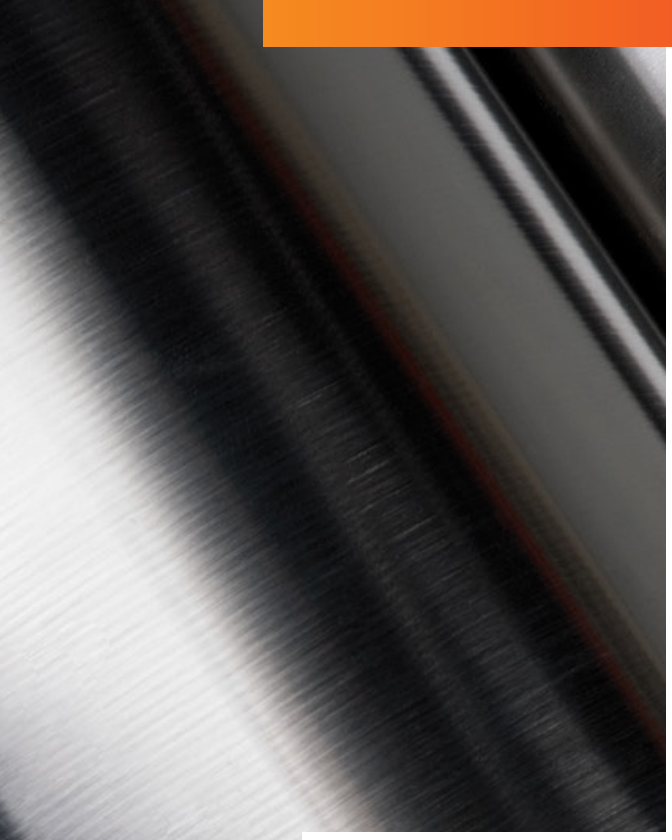
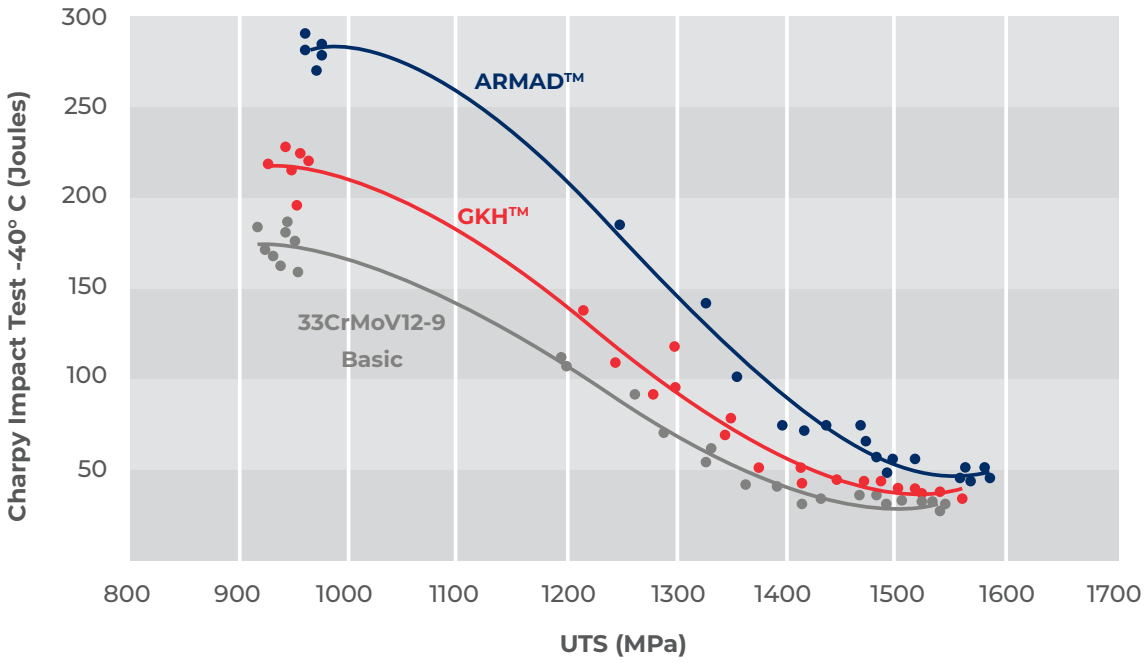


> ALLOY DESIGN

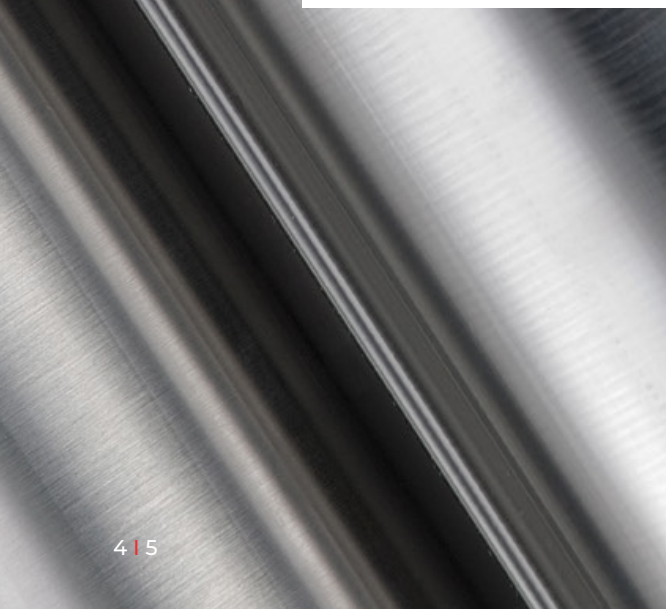
ARMAD™ is a steel grade with an alloy design based on Aubert & Duval GKH™. ARMAD™ contains very low residual elements due to the state-of-the-art steel making process control. Optimized molybdenum content (around 1%) improves mechanical properties after quenching and tempering heat treatment and increases the steel's hardenability. ARMAD™'s lower silicon and manganese content improves also the balance between strength and toughness.

> CHARPY IMPACT TOUGHNESS TEST



Change in toughness at -40° C according to strength for ARMAD™, GKH™ and Standard 33CrMoV12-9.

** GKH™: steel developed by Aubert & Duval and used for the FAMAS assault rifle barrel*



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> CHEMICAL COMPOSITION (weight %)

	C	Si	Mn	S	P	Ni	Cr	Mo	V
Mini	0.30	≤	≤	≤	≤	≤	2.80	0.70	0.15
Maxi	0.35	0.20	0.25	0.001	0.005	0.30	3.20	1.20	0.35

- ARMAD™'s chemical composition remains based on a 3% Cr, GKH™ steel*.
- Very high purity, due to furnace loading quality control
- Very low phosphorous and sulfur content, due to melting process
- Higher molybdenum content
- Lower silicon and manganese

> PHYSICAL PROPERTIES

Density at 20°C (68°F)

- 7.84

Mean coefficient of thermal expansion (α)

Temperature range	10^{-6}.m /m.°C	10^{-6}.in / in.°F
20°C-100°C, 68°F-212°F	11.8	6.55
20°C-300°C, 68°F-572°F	12.7	7.05
20°C-500°C, 68°F-932°F	13.6	7.55
20°C-700°C, 68°F-1292°F	14.2	7.88

Thermal conductivity (K)

Temperature	W/mK	Btu.in/hr.ft².°F
20°C, 68°F	35.5	248
200°C, 392°F	38.2	267
500°C, 932°F	38.9	272
600°C, 1112°F	41.2	288

Specific heat (C)

Temperature	J/kg.°C	Btu/lb.°F
20°C, 68°F	460	0.110
100°C, 212°F	500	0.119
200°C, 392°F	540	0.129

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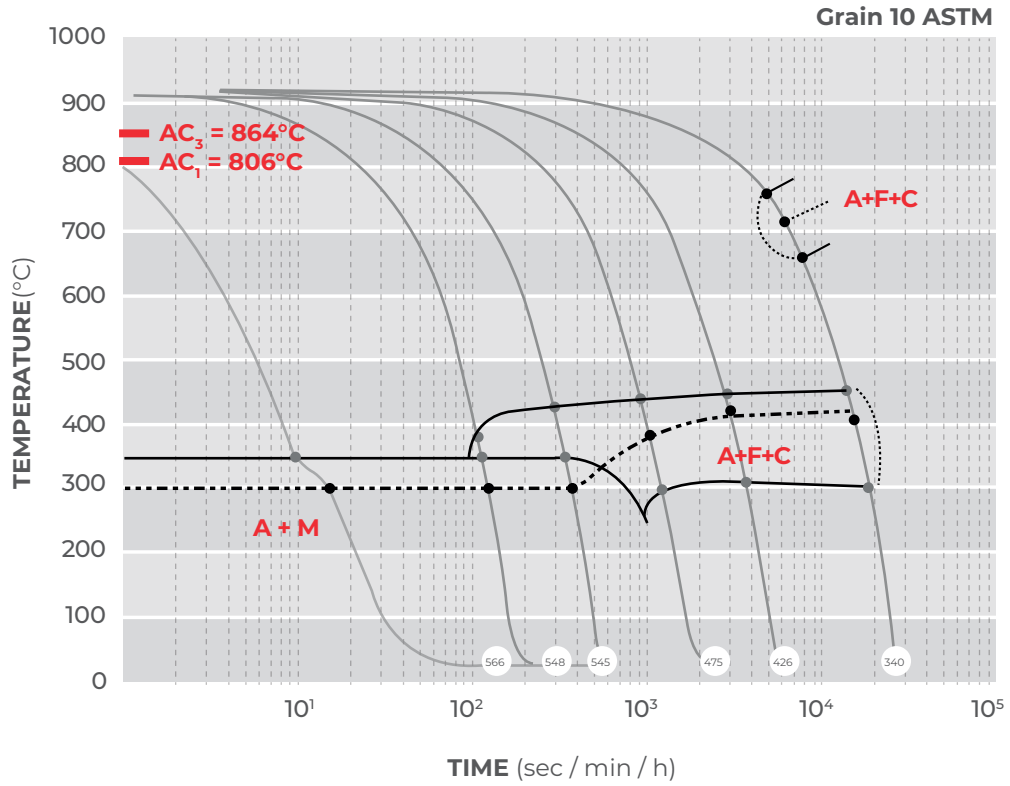
> TRANSFORMATION POINTS

Ac1	806°C, 1483°F
Ac3	864°C, 1587°F
Ms	375°C, 707°F

> CCT DIAGRAM



CCT Diagram (austenitization 920°C, 1688°F)

A : Austenite, F : Ferrite, C : Cementite, M : Martensite.

> MACROSTRUCTURE

The segregation, as measured on the ingots, complies with the tightest requirements. Below, are examples for air melted products.

	Severity for ARMAD™
Subsurface conditions	S2
Random conditions	R1
Center segregation	C2

Macrostructure according to ASTM E381

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> CLEANLINESS

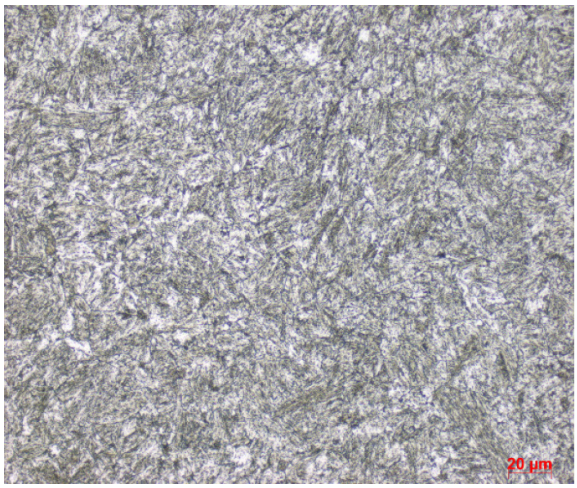
Micro-cleanliness complies with the tightest requirements.
Below, are examples of specifications met by ARMAD™.
Inclusion rating in accordance with ASTM E45 Meth A.

	A - Sulfide		B - Alumina		C - Silicate		D - Globular Oxide	
	Thin	Heavy	Thin	Heavy	Thin	Heavy	Thin	Heavy
ARMAD™	0.5	0.5	1.5	1.0	1.0	1.0	1.5	1.0

Beyond the specifications, Aubert & Duval's optimized melting practices makes ARMAD™'s micro-cleanliness value far better than standard 33CrMoV12-9 and usual engineering grades using same melting processes.

> MICROGRAPHIC CHARACTERIZATION

Quenched and Tempered material
Grade: ARMAD™
Austenitizing: 920°C, 1688°F
Oil quenching
Tempering: 625°C, 1157°F
Mean grain size: ≥ 7 ASTM



> MECHANICAL PROPERTIES

Delivery condition suitable for button riffling, cut riffling and cold hammering

Guaranteed longitudinal properties:

Hardness	280-325 HB 29-35 HRC	340-377 HB 36-41 HRC
UTS (MPa / KSI)	930/1080 (134/156)	1150/1280 (166/185)
YS (MPa/ KSI)	≥ 750 (108)	≥ 1000 (145)
EL (%)	≥ 15	≥ 15
KV (RT) J (ft-lb)	≥ 170 (125)	≥ 135 (99)
KV(-40°C/°F) J (ft-lb)	≥ 150 (110)	≥ 120 (88)

Garanteed Mechanical Properties after Cold Hammering to 43/46 HRC:

Barrels for military applications are most often cold hammered for better resistance and formation of the riffles in the bore.

Hardness	400-435 HB 43-46 HRC
UTS (MPa / KSI)	1350-1500 (196/218)
YS (MPa/ KSI)	≥ 1000 (145)
EL (%)	≥ 14
KV (RT) J (ft-lb)	≥ 80 (60)
KV(-40°C) J (ft-lb)	≥ 40 (30)

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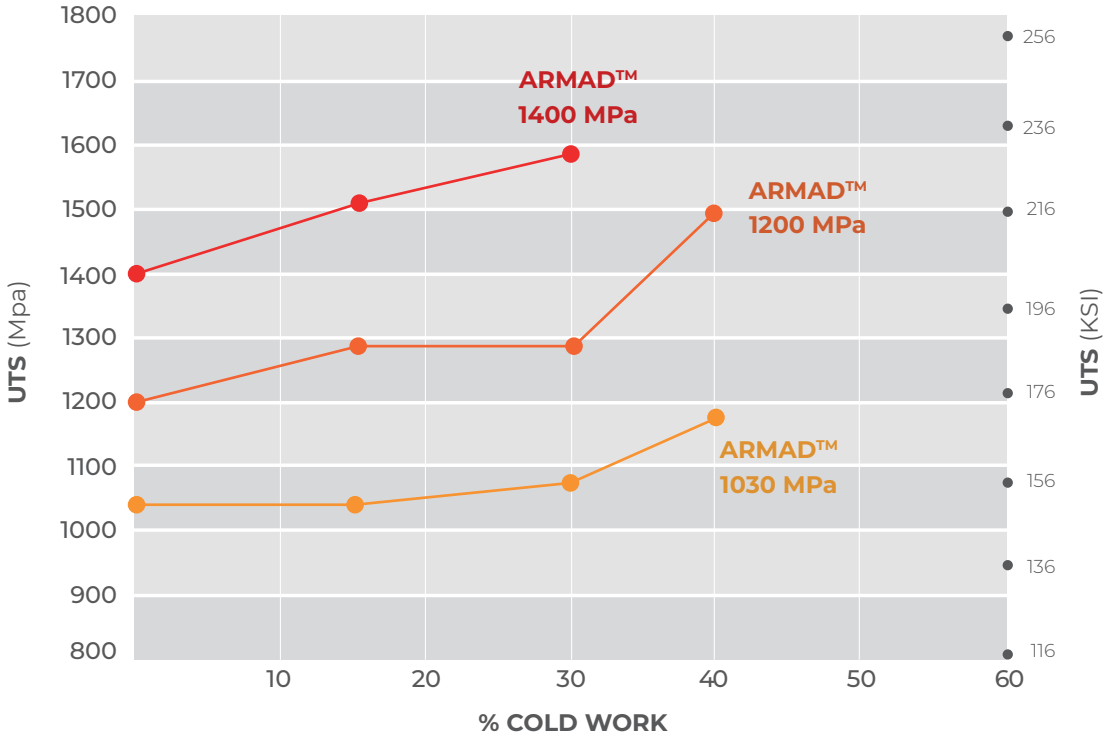
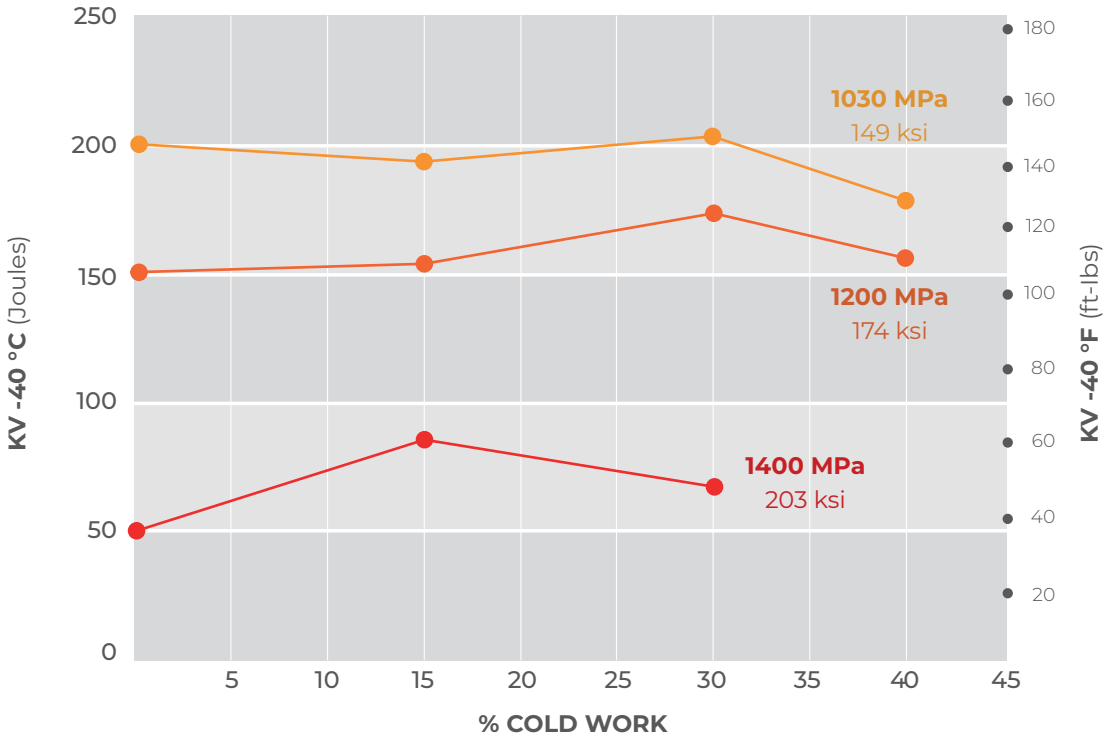
Evolution of ARMAD™ properties with cold hammer forging rate:



Influence of % cold work on KV (-40°C) values



ARMAD™ can be cold hammer forged with deformation up to 40% without loss of ductility. Chamber and barrel can be forged in same operation for an increased hardness in the chamber.

> APPLICATION IN DEFENSE / FIREARMS ARMAD™ FOR GUN BARRELS

Functions for gun barrels

Gun barrels are designed to withstand the high pressures and temperatures generated during firing. High yield strength levels (both at room and elevated temperature) combined with good ductility and toughness are required.

Problems on barrels	Barrel degradation modes	ARMAD™ properties
Permanent bore expansion	Maximum pressure developed in combustion chamber	0.2% Proof strength at room and elevated temperature
Barrel rupture under extreme testing	Extreme gas pressure	No brittleness but plastic ductility at RT and low temperature High Charpy-V energy and low transition temperature
	Obstruction tests	
	Torture tests at low temperatures	
Unacceptable loss of material resulting in bore ovalization, lack of muzzle velocity, lack of accuracy	After thousands firing cycles, growth and coalescence of micro-cracks	Good resistance to thermal fatigue
	Action of hot gases at high velocity	Resistance to erosion wear due to gas (combination of thermal, mechanical and chemical causes)
	Interaction of projectile with barrels wall when moving through the bore	Resistance to abrasive Wear (mechanical degradation) - High surface hardness

For this application, air melted ARMAD™ offers the best high strength / toughness compromise on the market. The specification we usually deliver for a cold hammering / Gun drilling and rifling processes are given above.

Other Ultimate Tensile Strength levels can be achieved and released depending on customer need and forming capacity (cold hammering or rifling).

It has been clearly demonstrated that ARMAD™ brings additional value compared with standard CrMoV grades:

Benefits to firearm producer/designer:

- ARMAD™ has been designed to maintain ductility at cold forging percentage reduction beyond 30%
- Hammer forging the chamber and the bore in the same operation results in more cold working and higher hardness in the chamber
- Use fatigue/strength upgrading opportunities of ARMAD™ to design lighter barrels with thinner wall sections
- During hammer forging, ARMAD™'s homogenous microstructure insures consistency in the formation of rifling and chamber
- Better tempering resistance for ARMAD™ compared to former 3%Cr steel grades:
  - Increases softening temperature thereby improving resistance to high bore temperatures
  - Improving resistance to higher temperature propellant

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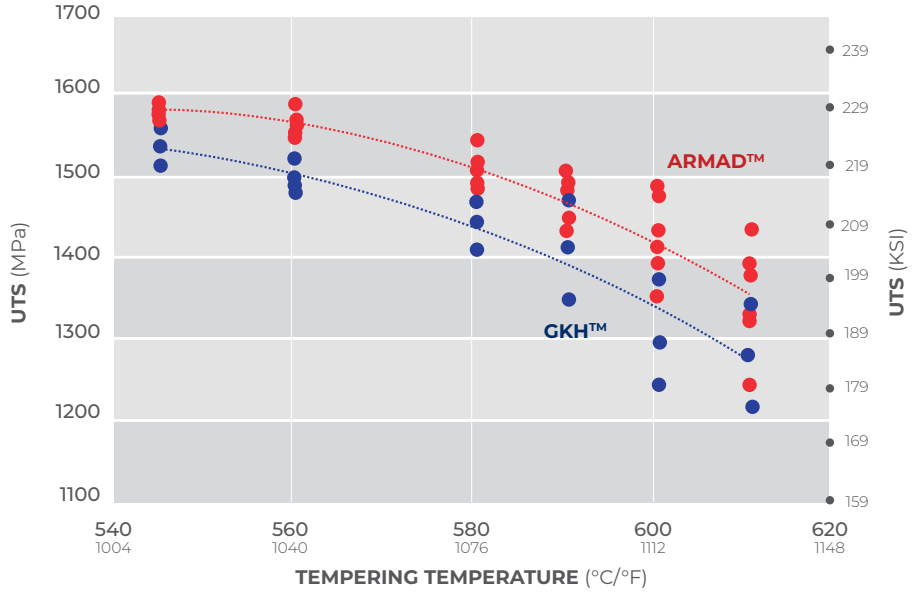
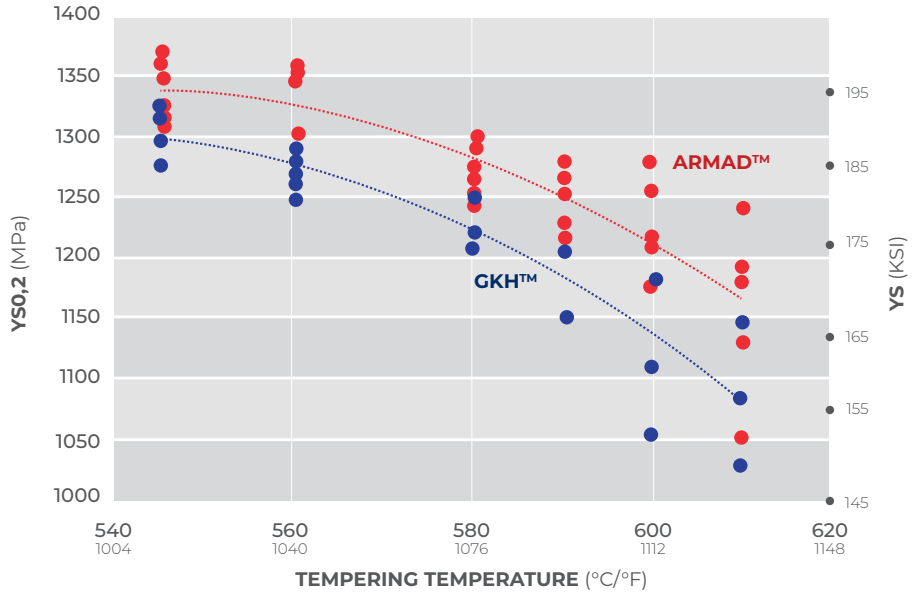
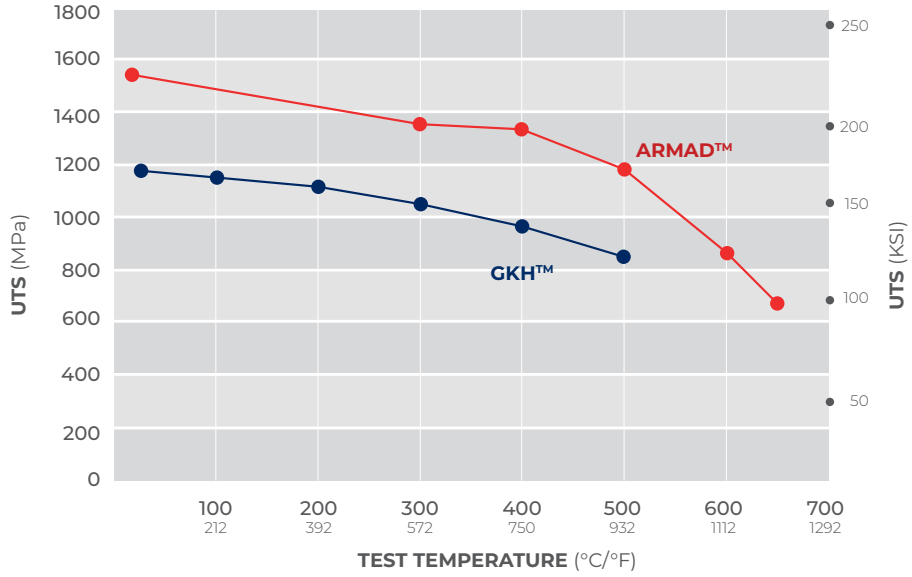
UTS Function of tempering



YS0, 2 Function of tempering



Elevated temperature tensile tests



> BEHAVIOR OF ARMAD™ MATERIAL DURING FIRING

Independent testing using military standard protocol and firing schedules has been conducted to determine the comparative wear and performance of M240 barrels manufactured from three different materials:

- MIL-B- 11595 E spec material, heat treated 28/32 HRC
- Aubert & Duval GKH™ material, heat treated 28/32 HRC
- Aubert & Duval ARMAD™ material, heat treated 38/42 HRC.

Barrels design and testing guidelines

M240 barrel (7,62mm cal.) button riffled and hard Chromium plated bores.

The endurance test schedule from the M240 prescribed in the governing military specification (MIL-DTL-63314) was selected as it is considered a standard test for barrel life evaluation.

Each barrel was be subjected to the same firing schedule for 20,000 rounds with periodic targeting, and muzzle velocity recordings. Each barrel was to be fired 250 rounds in 10-12 round bursts followed by a few seconds cooling. When 250 rounds were reached, the barrel was removed and cooled to ambient temperature before continuing the test.

MIL-B-11595, GKH™, ARMAD™ barrels before firing

MEASUREMENTS AND DATA COLLECTION EVERY 1,250 ROUNDS

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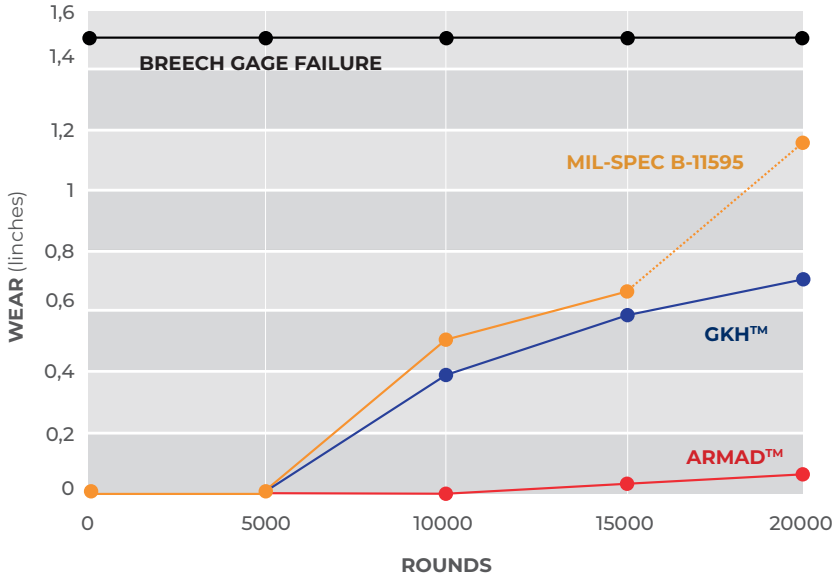
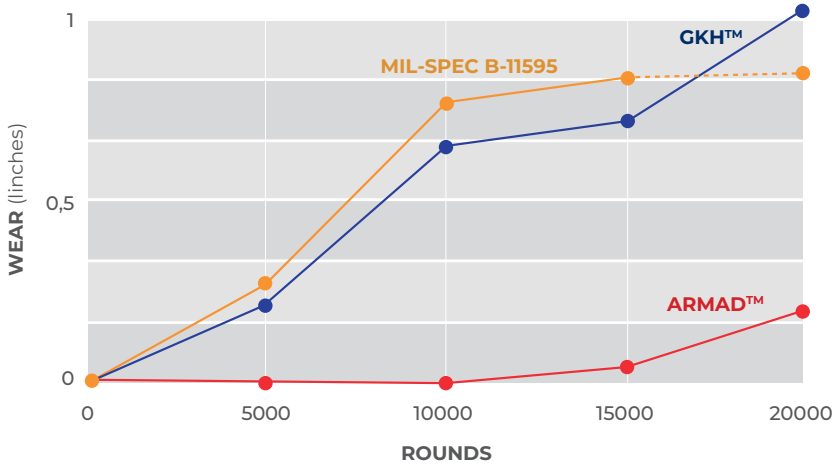
Test results

Breech bore erosion



ARMAD™ barrel has very limited erosion in breech bore in comparision of GKH™ and MIL-SPEC material. Breech bore erosion for MIL-SPEC barrel was too high to evaluate for 20 K rounds.

Throat bore erosion

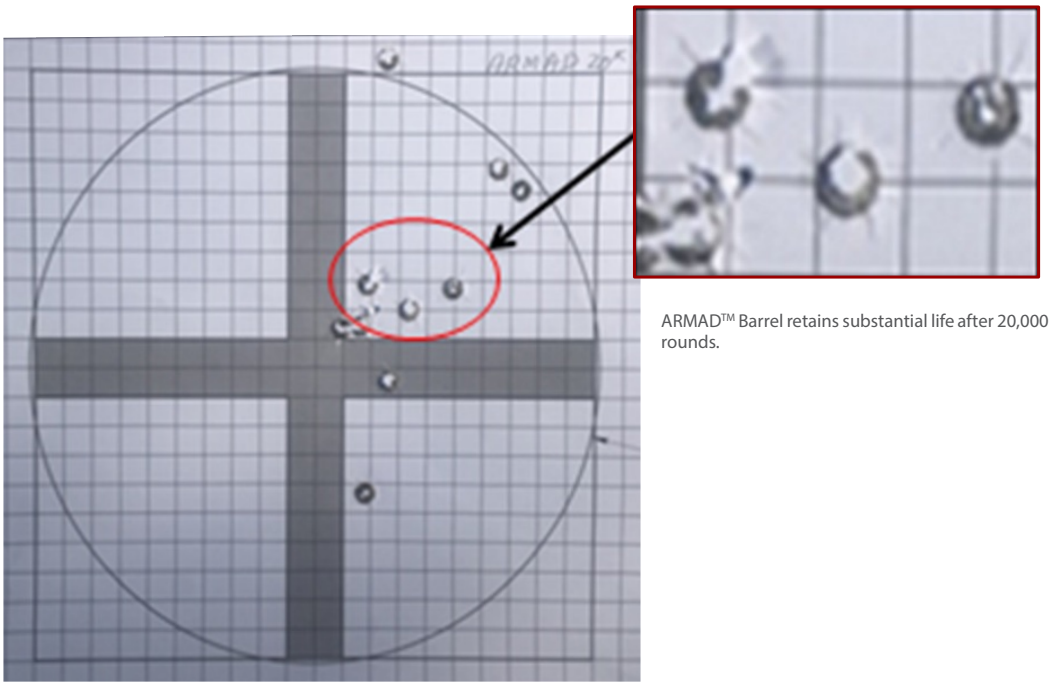


Target data

After 20,000 rounds the ARMAD™ and GKH™ barrel fire/target test data (Velocity, Extreme Spead, Yaw) indicated both barrels were 100% effective.

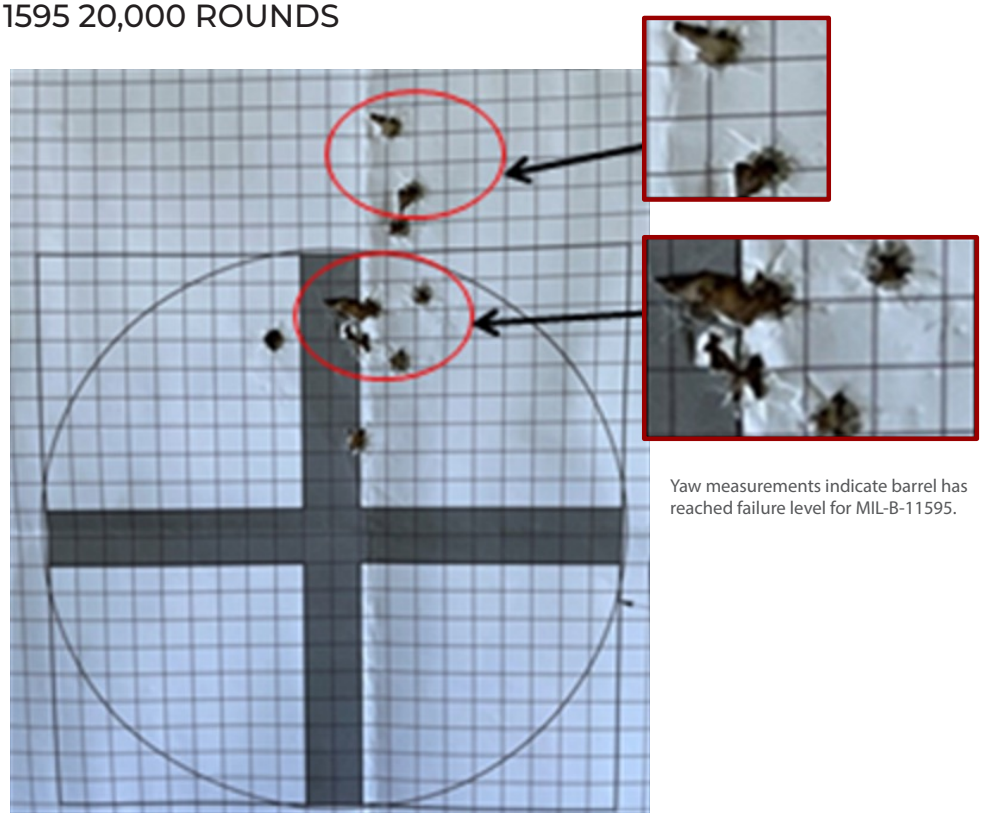
However as a result of significant bore wear, the MIL-B-11595 barrel data indicates barrel failure because of 30/40% of the projectiles had a Yaw of 15 degrees or more.

ARMAD™ 20,000 ROUNDS



ARMAD™ Barrel retains substantial life after 20,000 rounds.

MIL-B-11595 20,000 ROUNDS



Yaw measurements indicate barrel has reached failure level for MIL-B-11595.

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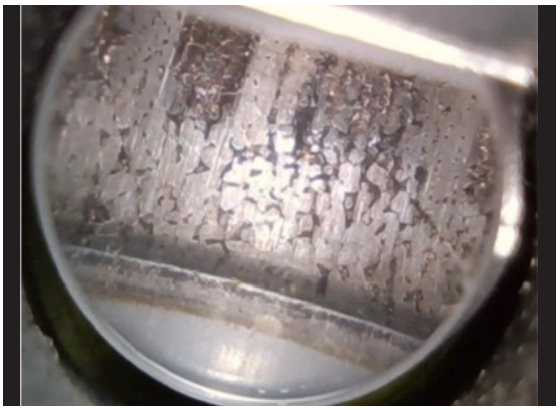
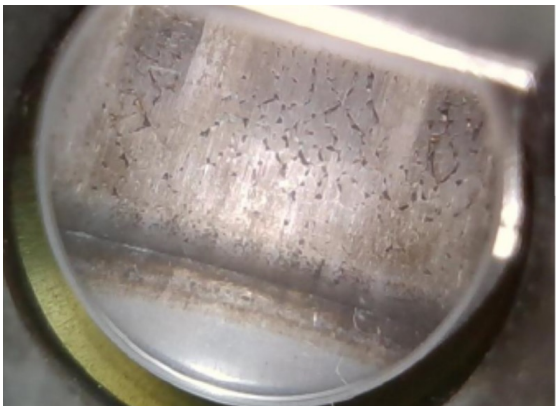
Pictures of the wear at the throat region subjected to the highest pressure, temperature and high speed gas:

Throat after 20k rounds

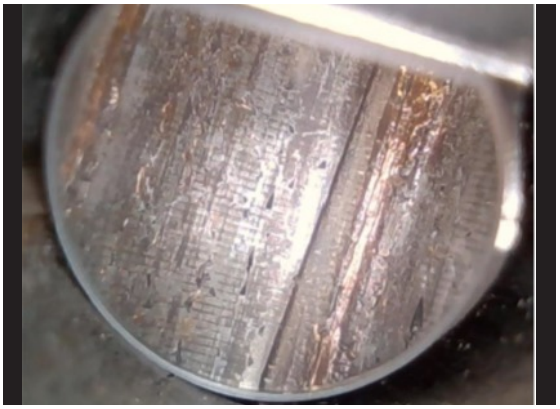


MIL-B-11595

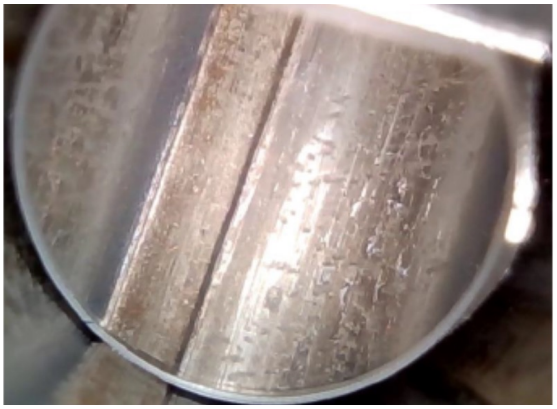


ARMAD™

Throat+1" after 20k rounds



MIL-B-11595



ARMAD™

Contact our technical team on www.aubertduval.com for more on the firing tests results.

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