WEAR RESISTANCE OF HIGHLY CROSSLINKED AND REMELTED POLYETHYLENES AFTER ION IMPLANTATION AND ACCELERATED AGING

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INTRODUCTION

- 1st Generation highly crosslinked polyethylenes have replaced historical and conventional polyethylenes:
  - ✓ High irradiation dose => Wear
  - ✓ Post-irradiation annealing/remelting => Oxidation

- Irradiation and Remelting worsen mechanical properties. Annealing does not guarantee complete oxidative stability

- UHMWPE/metal has worse wear performance than ceramic/ceramic bearings.

ION IMPLANTATION (II)

SURFACE MODIFICATION TECHNIQUE

METALS

POLYMERS, BIOMATERIALS

UHMWPE

- **II, Plasma II and Plasma Induced II**

N^+, H^+, He^+, C^+, Ar^+, and Xe^+

- **Fast Atom Beam (FAB)**

Ar, He, H and N

HARDNESS

ELASTIC MODULUS

WEAR RESISTANCE

WETTABILITY

HEMOCOMPATIBILITY

ANTICALCIFIC BEHAVIOR

RESISTANCE TO BIOFOULING

WHAT ARE THE EFFECTS ON

HIGHLY CROSSLINKED POLYETHYLENE?

OBJECTIVES

INFLUENCE OF ION IMPLANTATION

IONIC SPECIES

IMPLANTATION DOSE

HIGHLY CROSSLINKED/REMELTED PE

SURFACE MECHANICAL PROPERTIES

WEAR RESISTANCE

BEFORE/AFTER ACCELERATED AGING

HYPOTHESES

- Ion implantation would improve the surface mechanical properties and **wear resistance** of highly crosslinked and remelted polyethylenes (XPE).

- Ion implanted XPE would keep its wear resistance even after a severe oxidative challenge.

MATERIALS

UHMWPE GUR 1050

Compression Moulded (Perplas Medical)

Thickness 6 mm
∅ 12 mm

E-beam (100 kGy) **+** **Remelting (150 °C)**

Room Temperature; Air

Near vacuum, 2 hours, slow cooling

ION IMPLANTATION

Energy 90 keV, Base Pressure 3×10^{-7} mbar, Intensity 0.20 mA

IONIC SPECIES:

He^+ and N^+

DOSES:

5, 10 and 20×10^{15} ions/cm^2

MATERIALS

MATERIALS	IONIC SPECIES	DOSE (ions/cm^2)
NIMP	--------------------	--------------------
He05	He^+	$5x10^{15}$
He20	He^+	$20x10^{15}$
N05	N^+	$5x10^{15}$
N10	N^+	$10x10^{15}$

METHODS

ION IMPLANTATION SIMULATIONS

THEORETICAL

PENETRATION DEPTHS

IONIZATION RANGES

TRIM SIMULATIONS

He^{+} and N^{+}

90 keV

SURFACE MECHANICAL PROPERTIES

MICROHARDNESS

ELASTIC MODULUS

Ultramicrodurometer (Fischerscope H100)
Maximum load: 2 mN
20 steps (1 second each)

WEAR PERFORMANCE

PIN-ON-DISC TRIBOMETER (CSM Instruments)

Lubrication: distilled water
Temperature: 37 °C
Duration: 24 hours

Load: 5,23 N.
Ball (316L steel): 6 mm in radius
Circular track: 4 mm in radius
Sliding speed: 50 mm/s

BEFORE (AS-IMPLANTED) AND **AFTER AGING (120 °C/36h)**

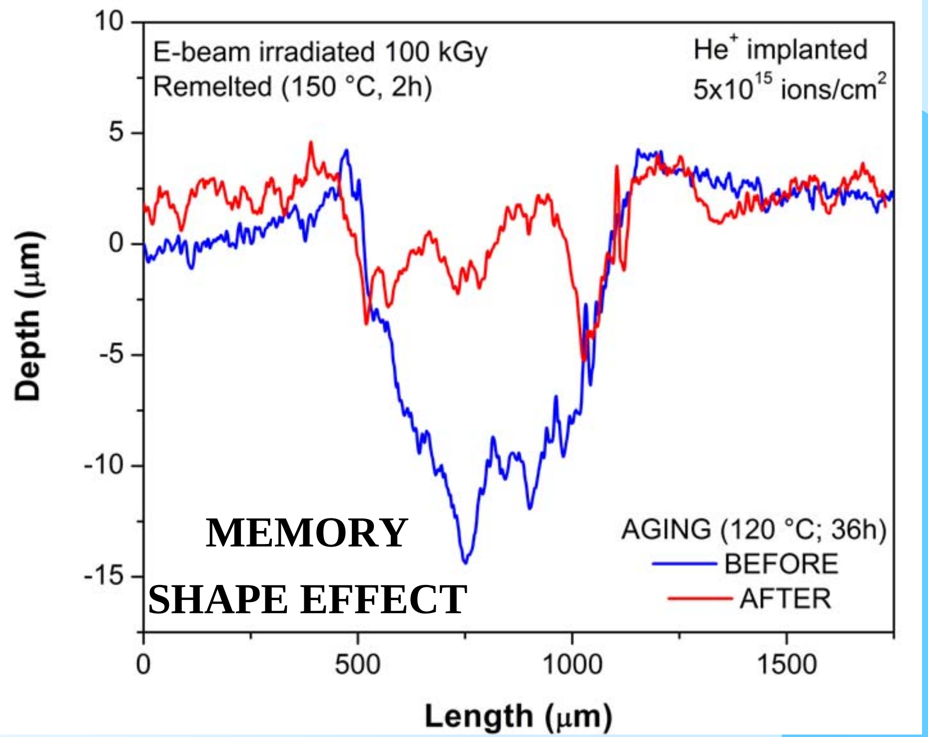
WEAR EVALUATION

Wear track area A_m

Profilometer VEECO DEKTAK3 ST

WEAR FACTOR

$$k = \frac{2\pi r A_m}{Ls}$$

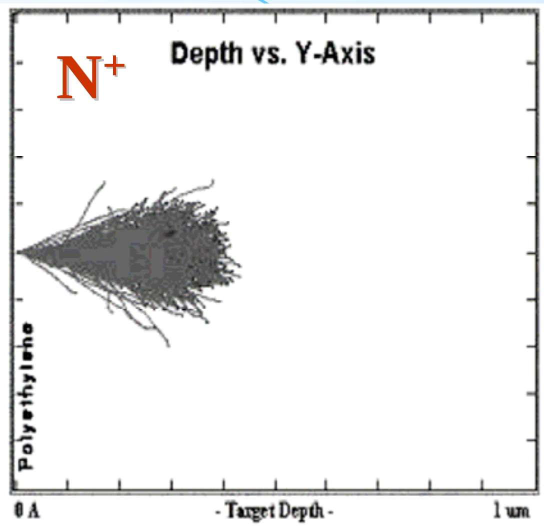


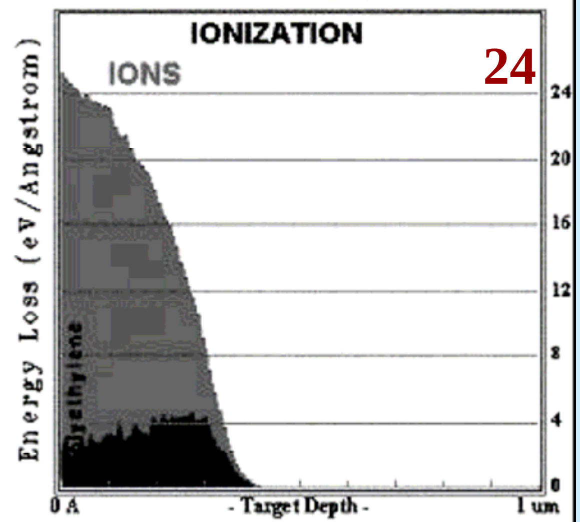
RESULTS

TRIM SIMULATIONS

N⁺ shallow penetration and less ionization

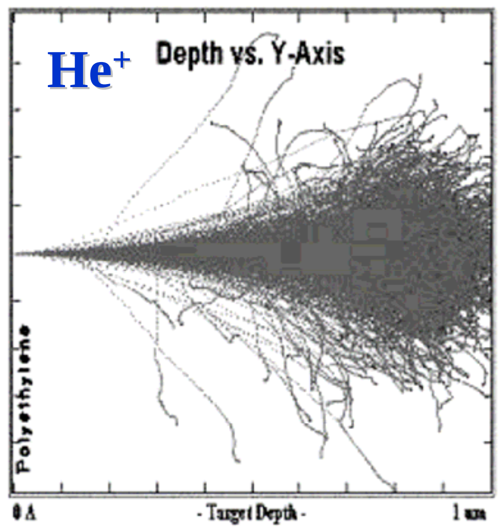
Greater scattering section
High chemical reactivity

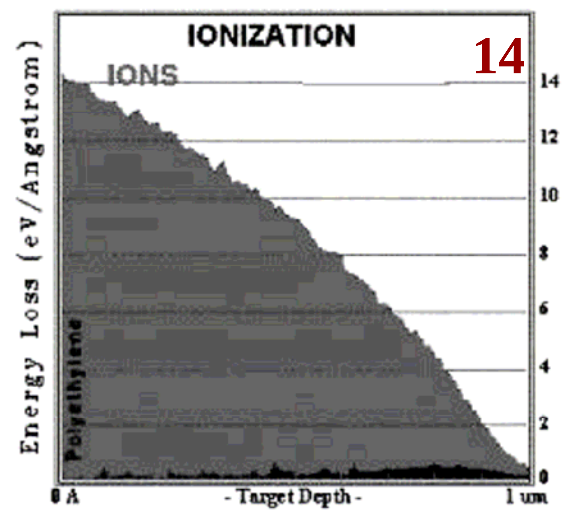




He⁺ higher penetration and ionization

Smaller scattering section
Low chemical reactivity





SURFACE MODIFICATIONS

Implanted surfaces changed to a yellowish/brownish color

NON-IMPLANTED

	$5x10^{15}$	$10x10^{15}$
He^+		
N^+		

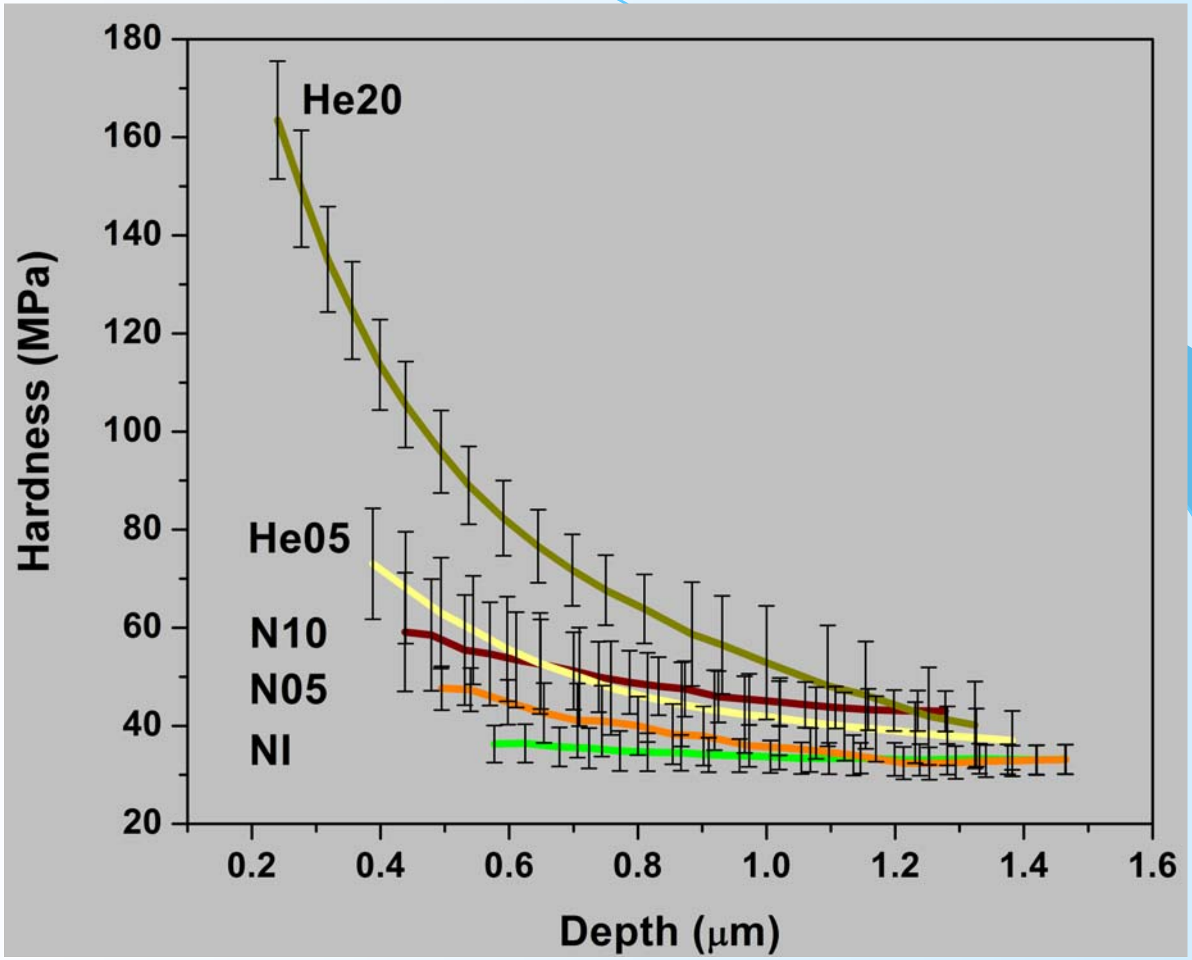
↑ m_{ion}

↑ Fluence

→ **DARKER COLOR**

SURFACE MODIFICATIONS

Increases in surface hardness and elastic modulus

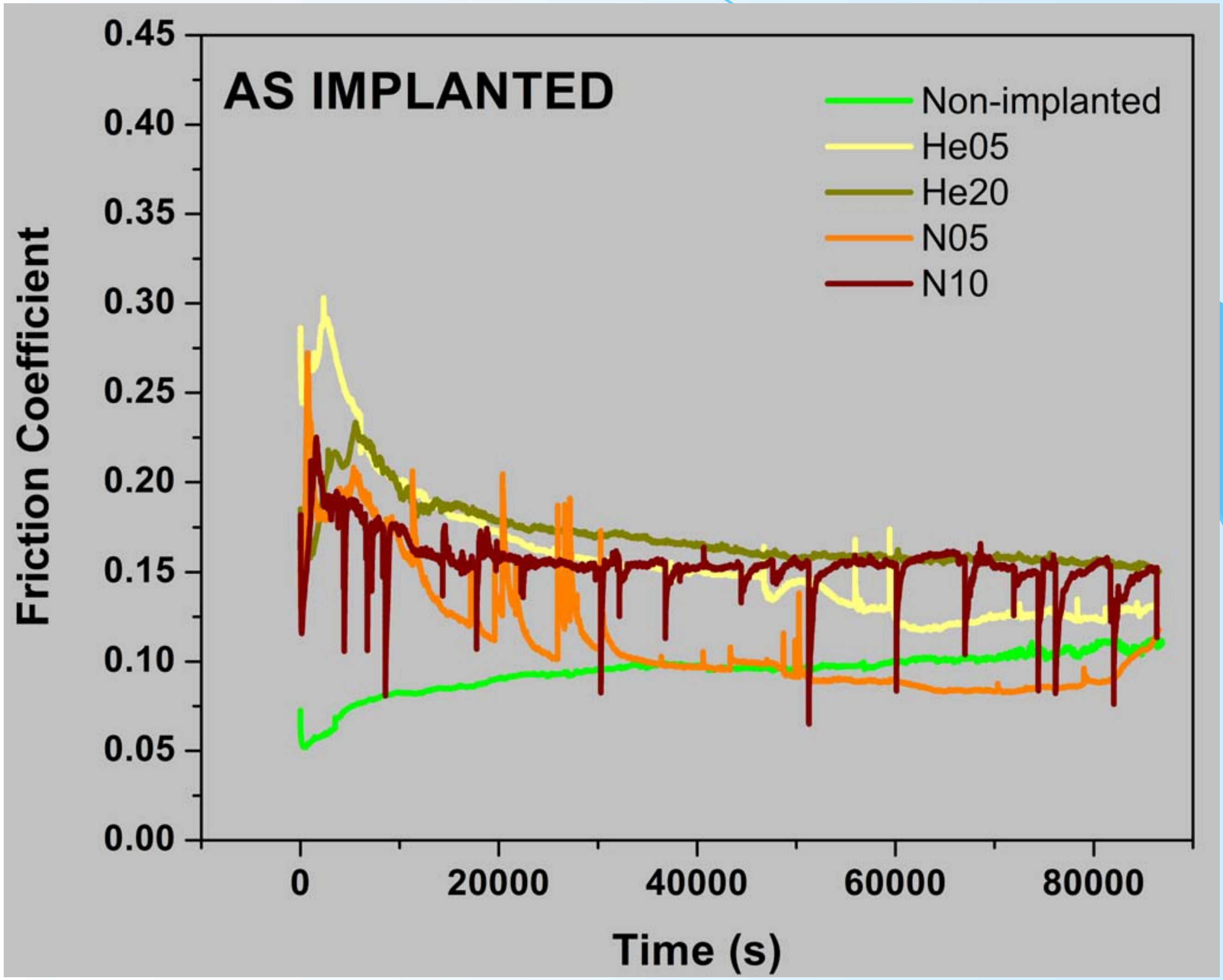


Helium implantation provided higher hardness

The higher the fluence, the harder the surface

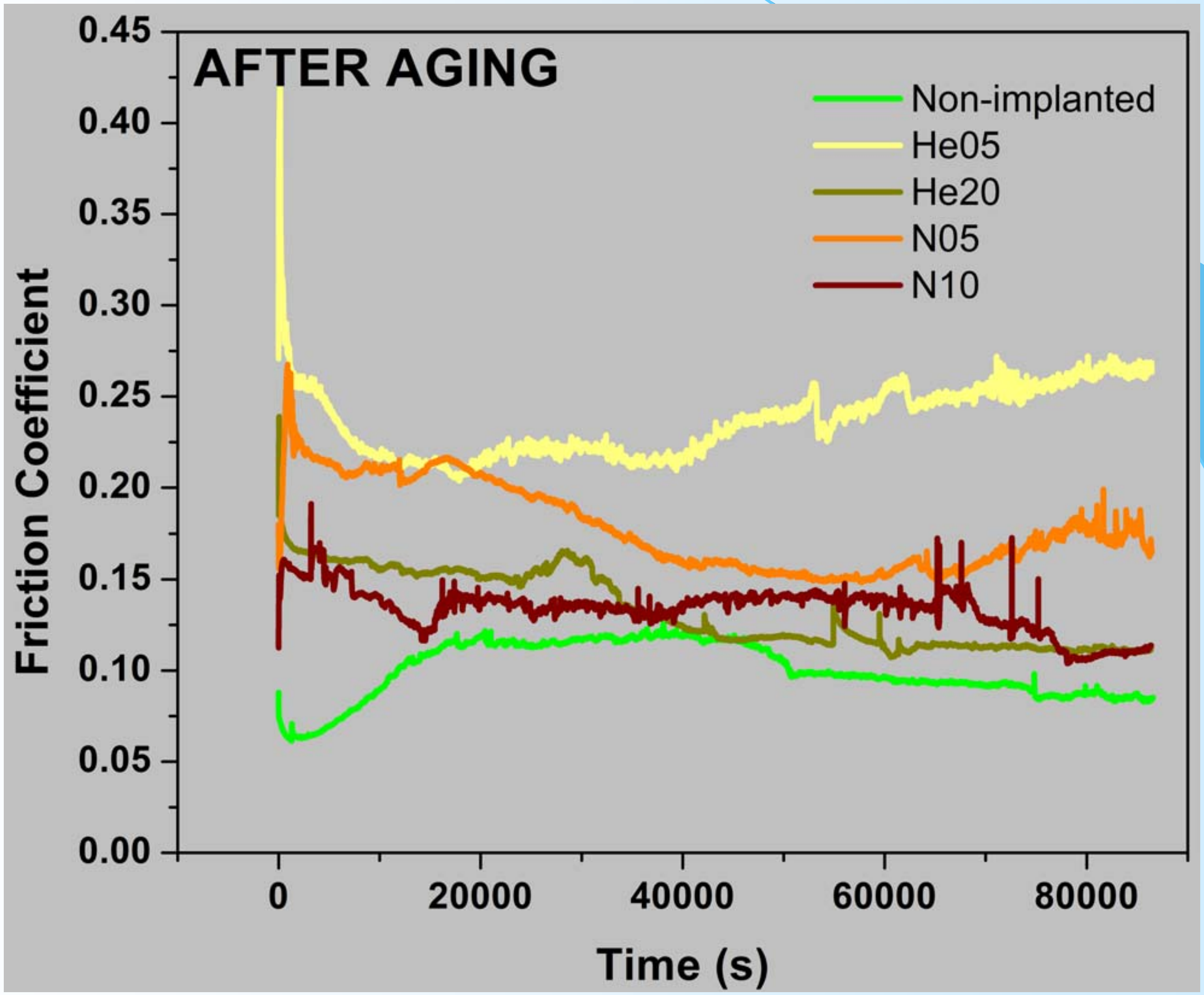
FRICTION COEFFICIENT RESULTS

Ion implantation implied higher friction coefficients



FRICTION COEFFICIENT RESULTS

Friction coefficients were affected by accelerated aging



WEAR FACTOR RESULTS

(10^{-6} mm^3/mN)

Ion implantation slightly improves wear resistance

MATERIALS	AS IMPLANTED	AFTER AGING
NIMP	2.6 ± 0.1	21.1 ± 0.4
He05	3.4 ± 0.3	26.2 ± 2.3
He20	1.6 ± 0.0	3.1 ± 0.1
N05	2.1 ± 0.4	8.5 ± 0.8
N10	1.1 ± 0.1	11.9 ± 1.0

DISCUSSION

POTENTIAL EFFECTS OF ION IMPLANTATION

- Extensive bond breaking and atomic displacement
  - ✓ Active free radicals, chain scission
- C-H bond breaking causes **dehydrogenation**
- New chemical bonds (C=C, etc.)
- **Surface crosslinking** (due to recombination of free radicals)
- Electronic stopping (He) vs. Nuclear stopping (N)

GRAPHITIZATION

DISCUSSION

- Ion implantation provoked changes in surface color and rose surface microhardness.
  - ✓ Massive surface crosslinking and graphitization
  - ✓ Hardening more prevalent for He^{+} (smaller scattering section and lower chemical reactivity)

- Ion implantation implied higher friction coefficients.
  - ✓ Hard surfaces and roughening effect.
  - ✓ Accelerated aging may change water absorption properties and load bearing capability

DISCUSSION

- Ion implantation improved wear resistance of XPE materials.
  - ✓ Correlation between wear resistance and crosslinking.
  - ✓ Slightly lower wear factors for N^+ (better bond strength)

- After severe oxidative challenge, implanted XPE (He20) exhibited better wear resistance than NI.
  - ✓ Implanted layer may work as a barrier to oxygen
  - ✓ Ion implantation may increase defects and oxygen concentration (N^+ induced more free radicals)

CONCLUSIONS

- Ion implantation increases surface microhardness

- Unimplanted XPE has the lowest friction coefficient.

- Ion implantation enhances wear resistance of XPE, even after severe oxidation.

FUTURE RESEARCH

- Study of the influence of ion implantation on fatigue properties of highly crosslinked and remelted PE

- To extend the current study to highly crosslinked and annealed PE

- Wear testing under conditions similar to those in total hip replacements (bidirectional tests / calf serum)

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