Polymers Are Rewriting the Rules of Mechanical Design

Many major engineering platform shifts have been accelerated by polymers replacing metal where it no longer makes sense. Automotive eliminated many metal bearings, bushings and tribology parts with engineering thermoplastics — cutting weight and cost while improving reliability. Medical devices replaced several machined steel components with acetal and PEEK — achieving tighter tolerances and lower friction at a fraction of the part cost. Electronics abandoned die-cast housings for injection-molded plastics — enabling miniaturization for innovation in smart phones. In each case the driver was the same: polymers delivered better system-level performance at lower cost, with design freedom that metal could not match. Humanoid robotics is the next frontier, and Delrin® is a material engineered for this transition.



> A humanoid robot must be lightweight yet strong.

The Challenge: Building Robots That Work in the Real World

Humanoid robots are no longer lab curiosities. Market-leading humanoid OEMs are transitioning from pilot programs to early production — and the materials choices being made right now will define which robots survive the move from demo to deployment.

The engineering demands are extraordinary. A humanoid robot must be lightweight yet strong, operate through millions of reliable cycles, tolerate continuous mechanical stress, maintain tight tolerances in compact joint geometries, and do all of this at a cost that supports commercial scale. No material category is more challenged by these demands than the structural and mechanical components found in robot hands, wrists, forearms and joints.

Why Delrin®? — The Engineering Case

Delrin® is a high-performance acetal homopolymer resin with a unique combination of properties that makes it particularly suited to the demanding mechanical environment inside humanoid robots and robotic hands.

The following hardware bottlenecks may concern humanoid and robot hand manufacturers:

Bottleneck	Impact on Production
Dexterity & manipulation reliability	~70% simple grasp success today; task failures destroy ROI
Component weight in distal joints	Every gram in hands/fingers increases arm inertia & energy draw
Material wear & fatigue	Hands must survive millions of cycles — metal and printed plastics fall short
Cost at scale	Actuators alone are 50–60% of BoM; every other component must work harder on cost

Delrin® – in Humanoid Robotics

Mechanical Performance

- High stiffness-to-weight ratio — significantly lighter than aluminum with competitive specific strength for non-load-bearing structural parts
- Outstanding fatigue resistance (Figure 1) — maintains performance through repeated cyclic loading, critical for finger flexion, gripper actuation and linkage mechanisms
- Low coefficient of friction and excellent wear resistance (Figure 2) — self-lubricating in dry sliding contact, ideal for gear teeth, cam surfaces, and bearing surfaces where grease is impractical
- Good impact resistance at room and low temperatures (Figure 3) — survives drop events and shock loading in robot falls

Figure 1. Flexural fatigue strength after one million cycles

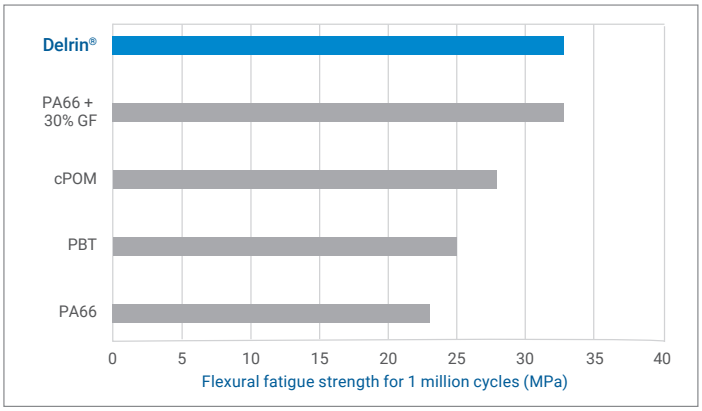
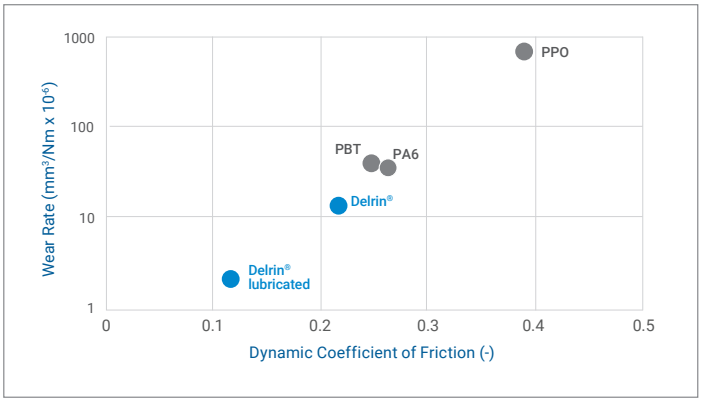
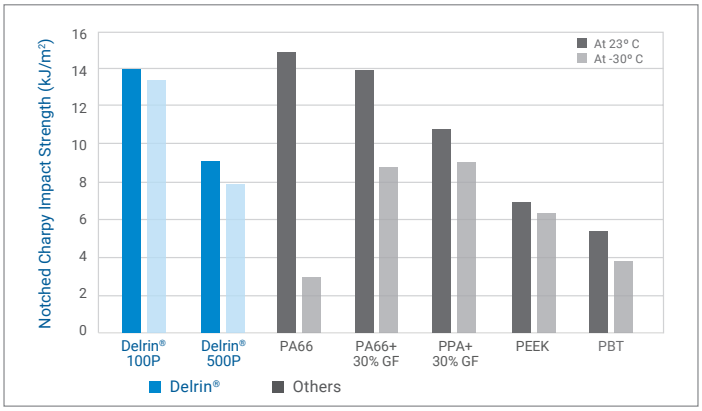


Figure 2. Wear rate and dynamic coefficient of friction comparison for various plastics on a steel countersurface[a]



[a]PV = 0.0675 MPa.m/s (P = 0.27 MPa and V = 0.25 m/s)

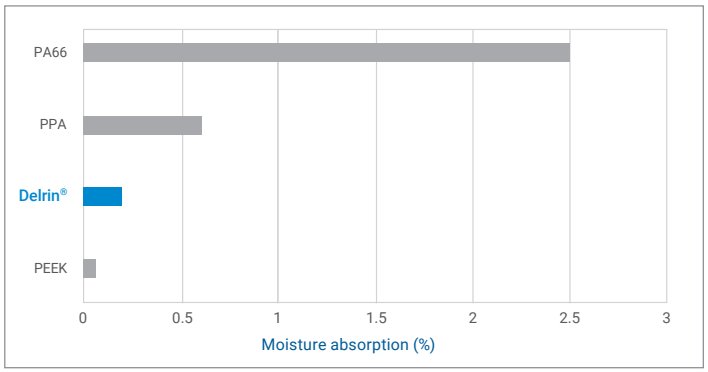
Figure 3. Impact strength at ambient (23 °C) and sub-ambient conditions (-30 °C)



Dimensional Stability

- Low moisture absorption vs. nylon (Figure 4) — maintains tight tolerances in humid environments and through thermal cycling
- Predictable, consistent behavior across operating temperatures from −40°C to +90°C — matching the thermal envelope identified in humanoid operational specifications

Figure 4. Moisture absorption of various plastics



Chemical & Environmental Resistance

- Resistant to fuels, solvents and cleaning agents (Table 1) — suitable for robots operating in industrial and food-adjacent environments
- Does not require surface treatment or coating to achieve functional performance

Table 1. Resistance to common chemicals, cleaners, and greases

Chemical / Media	Delrin®	Nylon (PA66) unfilled	Nylon (PA66) 30% GF	PBT	PEEK	PPA
Alcohols (Isopropyl alcohol, Ethanol)	🟢	🟠	🟠	🟠	🟢	🟠
Polar Solvents (Acetone, Methyl Ethyl Ketone)	🟢	🔴	🔴	🔴	🟢	🟠
Hydrocarbon solvents (Heptanes, Hexanes, Xylenes)	🟢	🟠	🟠	🟠	🟢	🟠
Bleach (NaOCl, typical dilute disinfecting)	🟢	🟠	🟠	🟠	🟢	🟠
Hydrogen peroxide (3% disinfecting)	🟢	🟠	🟠	🟠	🟢	🟠
Detergents (pH ~5–9)	🟢	🟢	🟢	🟢	🟢	🟢
Greases (Mineral oils / PAO / silicones)	🟢	🟢	🟢	🟢	🟢	🟢

🟢 = Compatible, 🟠 = Moderately compatible, 🔴 = Poor compatibility

Two Paths to Market: Prototype Fast, Scale Smart

One of Delrin's commercially compelling advantages is that it supports the full product development lifecycle — from the first prototype to high-volume production — using the same material and the same performance baseline.

Path 1: Machinable Stock Shapes for R&D and Low Volume

Delrin® is available in rod and sheet stock that can be CNC-machined to tight tolerances quickly and cost-effectively. For humanoid OEMs and their supply chains, this means:

- No tooling investment — parts are in hand within days, not weeks
- Design iteration is fast — revise CAD, re-machine, retest; the material doesn't change
- Performance is production-representative — properties of machined Delrin® closely match molded Delrin®, so validation data carries forward
- Ideal for finger phalanges, palm housings, pulley guides, tendon routing channels and sensor mounts — all components that change frequently during development but need real-world mechanical behavior

For small companies, start-ups and university research teams building open-source humanoids on limited budgets, machinable Delrin® stock shapes offer a direct route from design file to functional hardware without the overhead of casting or forming tools.

Path 2: Injection Molding for Cost-Effective High Volume

As production scales — from hundreds to tens of thousands of units — Delrin® transitions seamlessly into injection molding, enabling:

- Dramatic per-part cost reduction — a component that is expensive to machine can be produced much more economically through molding, especially at higher volumes
- One-shot net-shape manufacturing — complex geometries, undercuts, snap fits and integrated features produced in a single operation with no secondary machining
- Consistent, repeatable quality — injection molding tolerances are well-suited to gear teeth, bearing housings and precision linkage components
- Cycle times of seconds — supporting the production velocities humanoid OEMs will need as they scale toward thousands of units per month

This dual-path capability — prototype in machinable stock, scale in injection molding — eliminates the material transition risk that plagues teams that develop in one polymer and produce in another.

Delrin® – in Humanoid Robotics

Specific Applications in Humanoid Robots

Component	Why Delrin®
Finger phalanges & knuckle joints	Low weight, machinability, fatigue resistance through millions of flexion cycles
Tendon routing guides & pulleys	Self-lubricating, low friction, wear-resistant contact surfaces without grease
Gripper jaw bodies & end effectors	Stiff, dimensionally stable, easy to machine or mold to complex profiles
Wrist & forearm housings	Lightweight alternative to aluminum; moldable to net shape at volume
Gear blanks & small spur gears	Excellent for low-to-medium load gear sets in finger actuators; runs dry
Sensor mounts & PCB housings	Dimensional stability, electrical insulation, snap-fit integration
Cable management clips & guides	High fatigue life under repeated flex, low friction on cable jackets

The Cost Argument: Materials Must Scale with the Market

According to in-house assessments, the market inflection point for humanoid adoption is widely cited at **≤ US$20,000 per unit**. Achieving that threshold requires every component category to be optimized for cost at volume. Engineering plastics like Delrin® play a direct role in closing that gap.

Replacing machined aluminum housings and structural brackets with molded Delrin® parts can deliver significant **cost reduction on eligible components** while maintaining functional performance. In a typical robot with 40+ joints and hundreds of mechanical sub-components, even modest per-part savings compound rapidly across the BoM.

Delrin® does not replace metals in high-load structural joints or actuator cases, but it competes decisively in the large population of medium- and low-load components that make up a significant share of both cost and part count.

Property	Delrin®	Nylon (PA6/66)	PEEK	PPA
Moisture absorption	**Low**	High	Low	Low
Machinability	**Excellent**	Good	Difficult / costly	Moderate
Dry wear / friction	**Excellent**	Good	Very good	Moderate
Cost	**Low–Medium**	Low	Very high	High
Injection moldability	**Excellent**	Excellent	Specialist	Good
Fatigue resistance	**Excellent**	Moderate	Very good	Good

For components where **cost, machinability, low friction and moisture stability** are the governing requirements — which describes most of the robotic hand and forearm components — Delrin® is the material of choice.

DELRIN® CASE STUDY

Delrin® – in Humanoid Robotics

Delrin® delivers **70% of the tensile strength** of PEEK at just **5% of the cost**—a **95% cost savings** with minimal performance compromise.

For the vast majority of robotics applications—gears, housings, sliding components, structural brackets—Delrin® meets the mechanical brief while dramatically reducing material spend.

70%	95%	77%
tensile strength vs PEEK	cost savings vs PEEK	cost savings vs PPA

Data normalized to PEEK baseline. For design-critical applications, consult material data sheets.

Work With Delrin

Whether your team is machining first-article prototypes for a robotic hand or qualifying an injection-molding program for a fleet-scale humanoid deployment, Delrin offers:

- **Stock shapes** such as rods or plates for small volume and lab-scale projects
- **Application engineering support** for joint design, tolerance specification and grade selection
- **Material data** for simulation and FEA validated against real test specimens
- **Processing support** to optimize manufacturing efficiency and de-risk the ramp-up
- **Grades for specialized requirements** (i.e. easy processing, impact modified, low wear & low friction, reinforced, grades for regulated industries, and sustainability)

Contact us:
www.delrin.com

Robotics Landing Page:
www.delrin.com/robotics

Technical Data Sheets:
www.delrinmaterialcenter.com

Delrin – Engineering the Future, Together
To learn more, contact your Delrin representative or visit **Delrin.com**.

Delrin® is an industry-leading premium industrial polymer business. Grounded in strong innovation, Delrin is a category creator with a longstanding reputation for quality, reliability, supply and product performance. The iconic Delrin brand, coupled with proprietary technology and deep application expertise, make us a leader in the high-end engineering polymer market. Delrin has exciting growth prospects from exposure to automation, actuation, healthcare, mobility and consumer applications.

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