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## Crosslinked vs Thermoplastic Wire: Performance Differences in Harsh Environments

### Introduction

In mission-critical electrical systems, wire selection is not simply about conductivity; it is about performance under demanding environmental conditions. Whether in aerospace, defense, or industrial applications, wires must endure temperature extremes, chemical exposure, mechanical stress, and long service life without compromising safety or reliability. Two primary categories of wire insulation dominate these applications: **crosslinked (XL) and thermoplastic (TP)**. Each type offers distinct performance characteristics, advantages, and limitations. Understanding these differences is crucial for engineers tasked with designing systems that operate reliably in harsh and dynamic environments.

This paper provides a detailed comparison of crosslinked and thermoplastic wires, emphasizing their thermal performance, mechanical properties, chemical resistance, and suitability for high-reliability applications. A particular focus is placed on **how crosslink density influences performance parameters such as shrinkage, wrapback, and overall service life**, which are critical for long-term reliability.

### Overview of Wire Types

#### Crosslinked Wire (XL)

Crosslinked wire insulation is created by forming covalent bonds between polymer chains through chemical or radiation-induced crosslinking. Common materials include **XLPE (crosslinked polyethylene)** and **ETFE (crosslinked tetrafluoroethylene blends)**. The crosslinking process improves thermal stability, chemical resistance, and mechanical properties.

#### Typical Features:

- High temperature rating (typically 125–200°C)
- Superior resistance to solvents, oils, and fuels
- Excellent mechanical durability (abrasion, flexing)
- Retains shape after bending, reducing creep and deformation



## Thermoplastic Wire (TP)

Thermoplastic wire insulation is made from polymers that soften and flow when heated, such as **PVC (polyvinyl chloride)**, **FEP (fluorinated ethylene propylene)**, and **PTFE (polytetrafluoroethylene)**. TP wires are easier to process, can be molded or extruded, and are generally more cost-effective than crosslinked alternatives.

### Essential Features:

- Moderate temperature rating (typically 80–150°C)
- Easier to terminate and rework
- Good dielectric properties and electrical insulation
- Limited chemical and mechanical resistance compared to crosslinked wires

### Thermal Performance

Property	Crosslinked (XL)	Thermoplastic (TP)
Maximum Operating Temp	125–200°C	80–150°C
Melting Point	Does not melt; softens slowly	Melts/softens quickly
Thermal Aging Resistance	Excellent	Moderate
Long-Term Creep Resistance	High	Low–Moderate

**Insight:** Crosslinked wires outperform thermoplastic wires in extreme temperature environments. They resist deformation under heat stress, maintaining mechanical and electrical integrity for longer periods.

### Mechanical and Flexibility Considerations

**Crosslinked Wires:** High abrasion and flex resistance; excellent for high-vibration applications such as aircraft harnesses or missile systems. However, crosslinked insulation is harder to strip and requires special termination techniques.



- **Thermoplastic Wires:** Easier to handle and terminate; flexible at room temperature. Over time, repeated flexing or exposure to high temperatures may lead to cracking, deformation, or insulation breakdown.

### **Crosslink Density and Its Effects**

One of the defining characteristics of crosslinked wire is **crosslink density**, the number of covalent bonds between polymer chains. Crosslink density has a significant effect on three critical performance parameters:

#### **Shrinkage**

- Higher crosslink density reduces shrinkage at elevated temperatures, assuring that insulation retains its original diameter and continues to protect conductors effectively.
- Low crosslink density can result in excessive shrinkage, potentially exposing conductors and compromising dielectric integrity.

#### **Wrapback**

- Wrapback refers to the tendency of insulation to “wrap back” or retract after bending or mechanical stress.
- Crosslinked wires with optimized crosslink density resist wrapback, maintaining shape and minimizing stress on terminations.
- Thermoplastic wires, which have no permanent crosslinked structure, are prone to greater wrapback, increasing the risk of loosening in connectors over time.

#### **Service Life**

- Increased crosslink density correlates directly with longer service life. It improves thermal aging resistance, chemical stability, and mechanical robustness.
- In contrast, insufficient crosslinking accelerates insulation degradation under repeated thermal cycles or exposure to harsh chemicals.

### **Chemical and Environmental Resistance**

Crosslinked wires are superior in resisting fuels, oils, solvents, and other harsh chemicals. Thermoplastic wires can degrade when exposed to aggressive chemicals or UV light. Table below summarizes performance:



Environment / Stressor	Crosslinked (XL)	Thermoplastic (TP)
Fuel/Oil Exposure	Excellent	Limited
Solvents/Cleaners	Excellent	Moderate
UV / Ozone Exposure	High	Moderate
Moisture / Water Resistance	High	Moderate

**Insight:** In harsh operational conditions such as naval or aerospace environments, crosslinked wires provide a more robust solution with lower maintenance requirements.

### **Cost, Handling, and Installation Considerations**

While crosslinked wires excel in performance, they are more expensive and challenging to terminate. Thermoplastic wires are easier to process and are suitable for non-critical or moderate environmental applications. Designers must weigh performance versus cost based on mission requirements.

**Vital Consideration:** For systems where failure can result in mission compromise or safety hazards, crosslinked wire is generally preferred despite higher costs. For moderate environments with standard handling requirements, thermoplastic wire may suffice.

### **Conclusion**

Selecting the appropriate wire type for harsh environments is a critical engineering decision that directly impacts system reliability, safety, and longevity. **Crosslinked wires, particularly those with optimized crosslink density, provide superior thermal stability, chemical resistance, and mechanical durability**, guaranteeing minimal shrinkage, reduced wrapback, and extended service life. Thermoplastic wires, while easier to handle and more cost-effective, are best suited for moderate environments with lower thermal and chemical demands.

Ultimately, understanding the environmental stresses your system will face and the trade-offs between performance, handling, and cost, promotes optimal wire selection. The decision between crosslinked and thermoplastic wires is not merely about insulation material; it is about safeguarding system performance and personnel safety in the harshest conditions.