White Paper on Screw Element Material Selection for Twin-Screw Extruders

Screw Element Material Selection · Scenario-Based Engineering Guide

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1. Abstract

Co-rotating twin-screw extruders represent core equipment in polymer processing. The configuration and material selection of modular screw elements jointly dictate processing capacity, product quality, and operational economics. While industrial practice has established mature methodologies and engineering experience for screw configuration design, material selection for screw elements—an equally vital technical dimension—has long lacked a systematic, application-oriented selection guide.

Different material systems impose fundamentally different wear and corrosion mechanisms on screw elements during extrusion processing. Mineral fillers primarily cause abrasive wear, glass fibers are dominated by cutting wear, and PVC systems are primarily associated with hydrochloric acid corrosion. In the food and pharmaceutical industries, material safety and regulatory compliance are the primary constraints. Selecting the wrong material can, at best, shorten screw service life and increase downtime costs; at worst, it can result in product contamination and process instability.

The objectives of this white paper are to:

- Systematically define the ten typical application scenarios for screw element material selection in twin-screw extruders.
- Provide an in-depth analysis of the failure modes encountered by screw elements across each scenario.
- Establish the mapping and decision framework between application scenarios and material selection.
- Offer actionable selection methodologies to support daily engineering and technical decision-making.

2. Background and Objectives

2.1 Industry Status

Since its industrialization in the mid-20th century, twin-screw extrusion technology has been widely used in plastics compounding, masterbatch production, food processing, pharmaceutical and chemical processing, and other fields. According to industry statistics, annual demand for twin-screw extruders in the Chinese market alone exceeds 4,000 units, with plastics modification accounting for the largest share.

As downstream applications move toward higher performance, added functionality, and sustainability, processed material systems are becoming increasingly complex—severe duty conditions such as high filler loading, strong corrosion, and extreme abrasion keep emerging, placing ever higher demands on the material properties of screw elements.

2.2 Core Challenges

The key challenges the industry faces in material selection can be summarized as follows:

(1) Information asymmetry. Equipment manufacturers typically supply default material configurations (mostly nitrided steel and high-speed tool steel), which may not be tailored to the user's specific material system.

(2) Lack of Scenario-Based Selection Guidance: Suppliers generally provide material property data (e.g.hardness), whereas engineers need application-oriented guidance on which material to choose for each specific scenario.

(3) Insufficient Total Cost of Ownership (TCO) Awareness: Procurement decisions are frequently guided by initial capital outlay, overlooking the comprehensive economic value of high-performance materials in extending service life, reducing downtime, and lowering scrap rates.

2.3 Document Positioning

This white paper is neither a treatise on materials science nor an equipment operation manual; rather, it is an application-oriented selection guide for engineering decision-making. The core question it addresses is: "Given my material and processing conditions, which material should I select for the screw elements, and why?"

3. Overview of Twin-Screw Extruder Screw Elements

3.1 Functional Role of Screw Elements

Twin-screw extruders utilize modular (building-block) screw designs, wherein an entire screw comprises dozens of independent screw elements keyed onto a splined shaft. The type, arrangement, and combination of screw elements (termed “screw configuration”) directly govern the physical processes the material undergoes during extrusion, including conveying, plasticization, mixing, degassing, and compression.

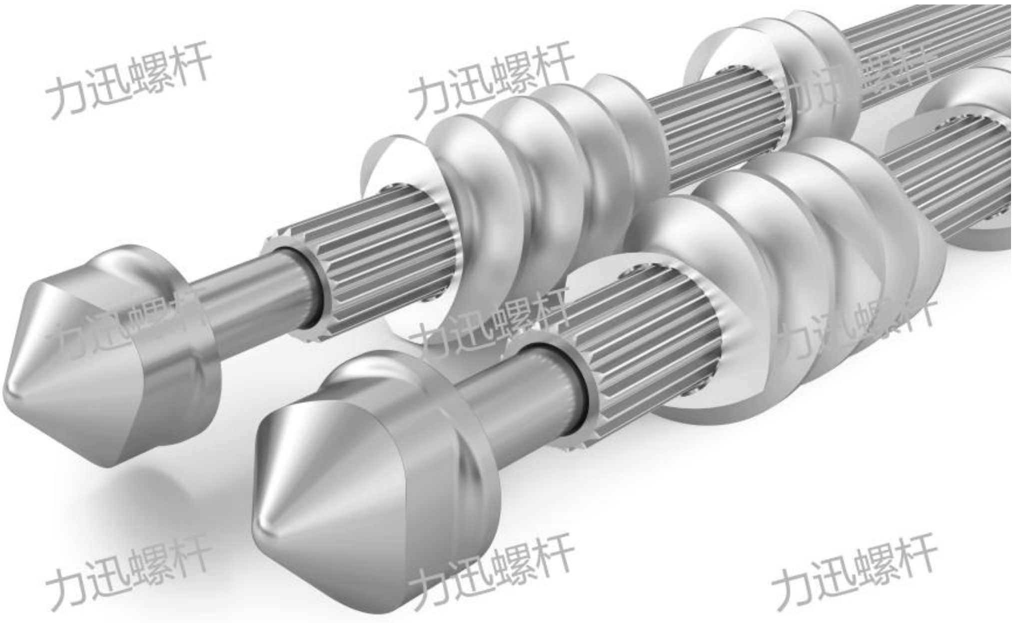

Figure 1. Assembly Diagram of Twin-Screw Shafts and Screw Elements

3.2 Main Types of Screw Elements

Element Type	Function	Typical Geometric Features
Forward-conveying element	Conveys material toward the die	Threaded structure with variable lead
Reverse-conveying element	Restricts conveying, builds pressure, provides sealing	Opposite hand to the forward element
Kneading block	Core element for dispersive and distributive mixing	Assembled from stacked discs at staggered angles of 30 – 90°
Toothed mixing element	Mixing dominated by extensional flow	Regularly arranged toothed openings on the disc

Special conveying element	Increase conveying in the feeding zone and reduce the degree of fill in the degassing section.	Wider flights, deeper channels

3.3 Service Environment of Screw Elements

During extrusion, screw elements are simultaneously subjected to multiple types of stress:

- Mechanical stress: torque, pressure
- Thermal stress: high-temperature environment (100-420 °C, depending on material) and localized shear heating
- Chemical stress: chemical attack from decomposition products, additives, moisture, and solvents
- Wear stress: continuous friction and cutting by solid fillers, reinforcing fibers, and impurity particles

The superposition of these stresses constitutes the core challenge in material selection for screw elements—dominant stress types and magnitudes vary significantly across application scenarios.

3.4 Failure Modes of Screw Elements

Typical failure modes of screw elements include:

- Surface wear: flight thinning, increased radial clearance, reduced output
- Surface corrosion: pitting corrosion, uniform corrosion, stress corrosion cracking
- Deformation and creep: permanent deformation under high temperature and high torque
- Fatigue fracture: crack initiation and propagation under cyclic stress

4. Part I: Definition and Analysis of Ten Typical Application Scenarios

Based on a systematic review of the downstream industries of twin-screw extruders, this white paper defines the following ten typical application scenarios. Each scenario is analyzed along four dimensions: product scope, process characteristics, industry standing, and the mechanical/chemical/thermal challenges imposed on the screw.

Scenario 1: General-Purpose Plastics Modification — Filling and Reinforcement

Scope of Application:

- Mineral-filled modification with calcium carbonate, talc, mica, etc. (matrix resins such as PP, PE, ABS)
- Glass-fiber-reinforced modification (PA, PP, PBT, PET, etc. glass-fiber content 15% – 60%)
- Carbon-fiber-reinforced modification (high-performance matrices such as PA, PPS)
- Functional masterbatch production (color, antioxidant, and conductive masterbatches, etc.)
- Thermally conductive plastics (alumina, boron nitride, graphene fillers)

Industry standing: This is the largest and most mature application scenario for twin-screw extruders; globally, twin-screw extruders used for plastics modification account for more than half of the total installed base each year.

Process Characteristics:

- Mineral fillers are introduced through the main or side feeder and require intensive dispersive mixing to break up agglomerates
- Glass fiber is introduced via the side feeder and requires gradual introduction and gentle mixing to preserve fiber length
- Typical L/D ratio: = 32:1–56:1
- Screw speed 300–1200 rpm

Challenges to the Screw — Wear as the Dominant Failure Mode:

Mineral fillers (calcium carbonate, Mohs hardness 3.0; talc, 1.0; quartz sand, 7.0) cause abrasive wear on the screw surface to varying degrees. Fillers with higher Mohs hardness produce more severe wear.

Glass fiber (diameter 10–20 μm, length 3–12 mm) produces continuous micro-cutting of the screw surface; particularly in the high-shear zones of kneading blocks, fiber ends act like miniature cutting tools, repeatedly scraping the metal surface.

Carbon fiber exhibits intermediate hardness and cutting behavior between the two; due to its smaller diameter (5–7 μm), its abrasive effect on the screw should not be overlooked at high loading.

Scenario 2: PVC Processing —Rigid PVC, Soft PVC

Scope of Application:

- Rigid PVC (uPVC): drain pipes, water supply pipes, electrical conduits, and uPVC window and door profiles
- Soft PVC: cable sheathing, film, artificial leather
- PVC dry-blend compounding and pelletizing

Industry standing: PVC is the world's third-largest commodity plastic by production volume, and China is the world's largest producer and consumer of PVC. PVC processing is one of the traditional core markets for twin-screw extruders.

Process Characteristics:

- Relatively low processing temperature (160–200 °C); the thermal sensitivity of PVC demands avoidance of local overheating
- Rigid PVC has poor flowability and requires sufficient plasticization and gelation within the screw
- Soft PVC contains a high plasticizer content (30%–60%) and strong material adhesion.

Challenges to the Screw — Corrosion as the Dominant Failure Mode:

When the processing temperature exceeds its thermal stability limit, PVC undergoes dehydrochlorination, releasing hydrogen chloride (HCl) gas. HCl is highly corrosive; in the presence of trace moisture it forms hydrochloric acid, causing severe uniform corrosion and pitting of steel.

In addition, halogen-containing additives (e.g.chlorinated paraffin flame retardants/plasticizers) and lead- or cadmium-based stabilizers (being phased out but still used in some developing countries) in PVC formulations further aggravate the corrosive environment.

Plasticizers used in large quantities in plasticized PVC (DOP, DOTP, etc.) may decompose at high temperature to produce organic acids, imposing additional chemical attack on the screw surface.

Key insight: In PVC processing, the primary cause of screw failure is corrosion rather than wear. Corrosion resistance should be the first priority in material selection.

Scenario 3: Specialty Engineering Plastics Processing

Scope of Application:

- High-temperature nylon (PPA, processing temperature 300–330 °C)
- Polyphenylene sulfide (PPS, processing temperature 300–340 °C)
- Liquid crystal polymer (LCP, processing temperature 300–420 °C)

- Polyetheretherketone (PEEK, processing temperature 360–420 °C)
- Fluoropolymers (PVDF, FEP, etc.)
- High-temperature PC, polyimide, etc.

Industry standing: Driven by the growth of high-end manufacturing sectors such as new-energy vehicles, 5G communications, aerospace and robotics, demand for specialty engineering plastics is growing rapidly. Processing these materials imposes the most demanding technical requirements on extrusion equipment and screw elements.

Process Characteristics:

- High processing temperature, up to 420 °C (LCP, PEEK)
- Some materials (PPS, fluoropolymers) decompose at high temperature to release corrosive gases
- LCP and PEEK have high melt viscosity and require the screw to withstand high torque loads
- Semicrystalline polymers such as PEEK demand extremely high temperature uniformity

Challenges to the Screw — Combined High-Temperature and Corrosion Failure:

In the 300–420 °C range, the hardness and strength of conventional alloy steels drop markedly (temper-softening effect). If screw elements soften, they not only lose wear resistance but may also undergo permanent deformation or even fracture under high torque.

Sulfur-containing gases generated from PPS decomposition can form sulfurous acid and sulfuric acid in a high-temperature oxidizing environment, causing chemical corrosion of metal surfaces.

Fluoropolymers may release hydrogen fluoride (HF) at high temperature, which is one of the most corrosive inorganic acids, posing a serious threat to almost all metallic materials.

Scenario 4: Thermoplastic Elastomer (TPE/TPV) Processing

Scope of Application:

- SEBS-based TPE (For automotive seals, sports equipment, medical devices)
- SBS-based TPE (For footwear, asphalt modification)
- TPU (thermoplastic polyurethane elastomer; for film, tubing, cable jacketing)
- TPV (dynamically vulcanized thermoplastic vulcanizate; for automotive seals and vibration damping components)
- POE-based elastomer

Industry standing: As substitutes for conventional vulcanized rubber and plasticized PVC, TPE/TPV are seeing continued growth in demand across automotive lightweighting, medical devices, consumer electronics, and other fields.

Process Characteristics:

- Extensive use of plasticizing oils (naphthenic/paraffinic oils), with oil loading reaching 40%–60%;
- TPV production involves dynamic vulcanization (cross-linking of EPDM within a PP matrix), with the extruder also serving as a reactor

- Adhesion and build-up of highly viscoelastic material on the screw surface are common processing issues
- Oil migration and bleeding require precise shear control and temperature management

Challenges to the Screw — Chemical Attack and Adhesion:

Prolonged exposure of plasticizing oil to metal surfaces at high temperature allows the aromatic and naphthenic components in the oil to cause surface swelling and chemical penetration into the screw material, accelerating the initiation of surface microcracks.

Micro-crosslinked particles generated by EPDM cross-linking during TPV production may form cured deposits on the screw surface, impairing surface finish and self-cleaning performance.

Peroxide cross-linking agents used in some TPE formulations are strongly oxidizing and impose additional chemical attack on the screw surface.

Scenario 5: Reactive Extrusion and Chemical Modification

Scope of Application:

- Maleic anhydride (MAH) grafting of polypropylene/polyethylene (PP-g-MAH, PE-g-MAH)
- Acrylic acid grafting modification
- Chain extension of recycled PET (rPET) for viscosity enhancement
- Chain-extension modification of polylactic acid (PLA)
- Bulk polymerization (polyamide, PLA, polyurethane)
- Compounding of polyacrylonitrile (PAN) carbon-fiber precursor

Industry standing: Reactive extrusion is one of the highest-value-added applications of twin-screw extruders, where the equipment serves not only as a processing machine but also as a continuous chemical reactor.

Process Characteristics:

- Requires precise control of the temperature profile, residence time, and shear intensity to ensure the reaction proceeds to the desired extent
- Usually requires vents to remove unreacted monomer, solvent, and reaction by-products
- Some reaction systems (e.g., PAN carbon-fiber precursor) employ high L/D twin-screw extruders (L/D > 64) to obtain sufficient residence time
- The rheological behavior of the material in the screw changes with reaction progress (viscosity may rise or fall sharply)

Challenges to the Screw — Chemical Corrosion and Fatigue:

Maleic anhydride can vaporize at processing temperatures, and its vapor poses a corrosive risk to metal surfaces. Reaction by-products (e.g., radical fragments from peroxide decomposition and organic acids) can also contribute to chemical corrosion.

Solvents used in PAN precursor preparation (e.g.DMF, DMSO) have high vapor pressure at high temperature and strong chemical permeation capability to the metal surface.

An ultra-high L/D ratio subjects the screw to greater cumulative fatigue loads, placing higher fatigue-resistance requirements on the material.

Scenario 6: Biodegradable Materials Processing

Scope of Application:

- PLA (polylactic acid) modification (toughening, heat resistance, crystallization-rate control)
- PBAT (poly(butylene adipate-co-terephthalate)) modification
- PLA/PBAT blend systems
- PBS (poly(butylene succinate)) and its copolymers
- Starch-based thermoplastic materials (TPS)
- PHA (polyhydroxyalkanoates)

Industry standing: Driven by plastic-restriction policies and carbon-neutrality goals, biodegradable materials are among the fastest-growing segments of the polymer industry. PLA and PBAT account for the largest shares of both production and consumption.

Process Characteristics:

- PLA and PBAT are highly moisture-sensitive and require thorough drying before processing (moisture content < 200 ppm); vacuum venting is required during extrusion.
- PLA is prone to thermal degradation and hydrolysis at high temperature; screw configuration and temperature control must avoid excessive shear
- PBAT has low melt strength, imposing special requirements on the pelletizing (cutting) system
- Starch-based materials have a narrow processing-temperature window and require a balance between melt plasticization and starch degradation

Challenges to the Screw — Hydrolytic Corrosion and Surface Quality:

The degradation products of PLA and PBAT include organic acids (lactic acid, adipic acid, etc.). In the presence of trace moisture, they create an acidic environment that causes slow but continuous chemical attack on the screw surface.

Starch-based materials may release sugars and organic acids during processing, increasing corrosion risk.

More importantly, biodegradable materials are widely used in film, fiber, and other color- and contamination-sensitive applications. The surface finish and cleanliness of screw elements directly affect product appearance quality. Any material retention and degradation caused by surface defects can lead to black spots, discoloration, yellowing, and other product defects.

Scenario 7: Food Extrusion Processing

Scope of Application:

- Extruded puffed snacks (potato chips, shrimp chips, corn puffs)

- Breakfast cereals (flakes, oat bars)
- Texturized vegetable protein products (plant-based meat)
- Pet food (dry, semi-moist)
- Aquatic feed
- Confectionery and chocolate products
- Functional foods with dietary fiber Dietary fiber-based functional foods

Industry standing: Food extrusion is the largest non-plastics application market for twin-screw extruders. The global food-extrusion equipment market keeps growing, with texturized vegetable protein as the most active emerging segment.

Process Characteristics:

- Wide operating temperature range (60–200 °C), depending on product type
- Materials often contain high moisture (20%–70% wet basis) and require cooking and expansion under high temperature and pressure
- Some products require low-temperature processing to preserve heat-sensitive components (e.g., probiotics, vitamins, and enzyme preparations)
- Equipment requires frequent cleaning; cleaning agents are typically alkaline or acidic solutions

Challenges to the Screw — Hygiene Compliance, Chemical Corrosion, and Frequent Cleaning:

Food-grade material compliance is a hard constraint. Screw elements must not migrate excessive heavy-metal ions (lead, cadmium, nickel, chromium, etc.) into food; the material must meet food-contact-material regulatory requirements

Processing highly acidic food raw materials (e.g.), juice concentrates and fermented products) creates an acidic processing environment, causing chemical corrosion of the screw surface.

Frequent cleaning procedures (alkaline cleaning + acid cleaning + water rinsing) impose cyclic chemical stress on the screw surface, accelerating the breakdown and regeneration of the passive film. Prolonged operation may lead to cleaning-in-place (CIP)-induced corrosion.

Scenario 8: Pharmaceutical Hot Melt Extrusion (HME)

Scope of Application:

- Solid dispersions of poorly water-soluble drugs (to improve bioavailability)
- Sustained- and controlled-release formulations
- Taste-masking formulations
- Transdermal drug-delivery matrices
- Implantable drug-delivery systems

Industry standing: Hot melt extrusion (HME) is one of the most important formulation technology advances in pharmaceutics over the past two decades. It uses a polymeric carrier to dissolve or uniformly disperse the active pharmaceutical ingredient (API) in the molten state, forming a solid dispersion that markedly improves the oral bioavailability of poorly water-soluble drugs.

Process Characteristics:

- Small production scale (from tens of grams at laboratory scale to tens of kilograms per hour at production scale);
- Extremely expensive materials (API may cost tens of thousands of CNY per gram)
- Processing temperatures typically 80–200 °C
- Zero tolerance for residue and cross-contamination
- The entire process must comply with GMP (Good Manufacturing Practice) requirements

Challenges to the Screw — Compliance and Zero Contamination:

Metal-ion leaching is the greatest risk in HME. Even trace migration of iron, nickel, or chromium ions into the API may trigger drug degradation, discoloration, or toxic impurities, scrapping the entire batch.

Material residue is the second-largest risk. Micro-scratches or rough areas on the screw-element surface may retain API residue from the previous batch and become a cross-contamination source in the next batch. Hence HME screws demand very high surface finish standards (typically Ra ≤ 0.2 μm or better), and the modular design must support rapid disassembly, thorough cleaning, and cleaning validation.

GMP compliance requires material traceability of the screw. From raw-material certificates and heat-treatment records to surface-treatment process parameters, all information must be fully documented and archived.

Scenario 9: Recycled Plastics Recovery and Processing

Scope of Application:

- PET bottle flake recycling and pelletizing (rPET)
- PE/PP film recycling and pelletizing
- Waste appliance plastics recycling (ABS, HIPS, PP)
- Engineering plastics (PA, PC, POM, etc.) recycling.
- Automotive plastics recycling.

Industry standing: Against the backdrop of the circular economy and carbon neutrality, the recycled-plastics industry is growing explosively. The EU plastic-packaging recycling target (55% by 2030) and China's dual-carbon goals together drive demand for high-quality recyclate.

Process Characteristics:

- Recycled feedstock inevitably contains impurities such as metal debris, sand and mineral particles, label adhesive residues, inks, and other types of plastics.
- PET flake processing requires deep dewatering and devolatilization (residual moisture, acetaldehyde, and other small molecules); vacuum vent design is critical.
- Recyclate quality varies significantly, requiring the extruder to provide high processing flexibility.

- High-throughput continuous lines (500–3000 kg/h) are becoming an industry trend

Challenges to the Screw — Extreme Abrasive Wear and Contaminant Impact:

Metal impurities (iron filings, aluminum chips, copper wire, etc.) and inorganic impurities (sand, glass fragments) in recovered material cause the most severe abrasive wear on the screw surface. These impurities are far harder than mineral fillers (quartz in sand has Mohs hardness 7) and are irregularly sized, producing a combined impact-and-cutting effect on the flight surface.

Residual moisture in PET bottle flakes vaporizes at extrusion temperature, generating high-pressure steam within the screw that imposing pulsating pressure loads on the screw elements and sealing structures.

Ink and adhesive residues in some recyclates decompose at high temperature to produce organic acids and halogenated compounds, constituting an additional chemical corrosion source.

Scenario 10: Powder Coatings and Thermoset/Magnetic Materials

Scope of Application:

- Epoxy/polyester hybrid powder coatings
- Outdoor pure-polyester powder coatings
- Acrylic powder coatings
- Phenolic molding compounds (bakelite powder / BMC / SMC)
- Epoxy potting compound premixing
- Magnetic plastics (NdFeB / ferrite magnetic powder + nylon/PP matrix)

Industry standing: Powder coatings are a key growth area of environmentally friendly coatings, with a clear trend toward replacing solvent-based coatings. Magnetic plastics are in strong demand for new-energy-vehicle motors, consumer electronics, and other applications.

Process Characteristics:

- Powder coatings are extruded at low temperatures (80–130 °C) but require precise shear control to avoid premature resin curing
- Thermoset materials are in the B-stage (partially cured) during extrusion and complete cross-linking through subsequent curing
- Magnetic plastics contain extremely high magnetic-powder loading (85%–92%); the material is nearly powder-like with very poor flowability
- Bakelite powder processing requires a constant-depth channel design to avoid premature curing within the screw

Challenges to the Screw — Extreme Abrasive Wear and Deposits:

NdFeB magnetic powder in magnetic plastics has a high hardness (Mohs hardness 5–6) and is present at very high concentrations (>85%), creating one of the most extreme abrasive-wear scenarios for the screw surface. In the industry, screw life in magnetic-plastics processing is generally the shortest among all application scenarios.

Once a thermoset resin precures (gels) on the screw surface, the resulting hard deposit is extremely difficult to remove and, in subsequent processing, acts as a hard abrasive that continuously wears the screw surface.
Inorganic pigments and fillers in powder-coating formulations, such as barium sulfate and titanium dioxide, are also common sources of abrasive wear.

5. Part II: In-Depth Analysis of Screw Element Failure Modes

Understanding failure modes is a prerequisite for proper material selection. Screw element failures can be categorized into four major failure mechanisms, each comprising several sub-mechanisms.

5.1 Wear

Figure 2. Typical Wear Patterns of Screw Elements

5.1.1 Abrasive Wear

Mechanism: Hard particles (mineral fillers, glass fiber, impurities) are pressed into the screw surface under pressure and, through relative motion, produce ploughing and cutting that form microscopic chips.

Influencing factors:

- Ratio of abrasive hardness to screw-surface hardness (H_abrasive/H_screw; hardness unit: HV): when the ratio exceeds 0.8 – 1.0, the wear rate rises sharply
- Abrasive particle size: Larger particles result in greater cutting depth per pass.
- Abrasive content: The higher the abrasive content, the higher the density of abrasive contacts on

the wear surface.

- Contact pressure: highest at the clearance between screw and barrel
- Temperature: high temperature lowers screw-surface hardness and indirectly accelerates wear

Typical scenarios: mineral-filled modification, recycled plastics processing, magnetic-plastics processing

5.1.2 Cutting Wear

Mechanism: Fiber ends (glass fibers, carbon fibers) act as microscopic cutting tools under high shear forces, repeatedly scraping the metal surface and producing micro-cutting.

Influencing factors:

- Fiber hardness
- Fiber content and length
- Shear rate (screw speed and kneading-block stagger angle)

Typical scenarios: glass-fiber-reinforced modification, carbon-fiber-reinforced modification

5.1.3 Erosive Wear

Mechanism: High-velocity particle-laden fluid impinges on the screw surface at a certain angle, producing a combined effect of fatigue spalling and micro-cutting.

Influencing factors: flow velocity, impact angle, particle hardness and shape

Typical scenarios: high-velocity-gas zones near vents, side-feeder introduction zones

5.2 Corrosion

5.2.1 Uniform Corrosion

Mechanism: Corrosive media uniformly attack the entire screw surface, causing uniform thinning of the surface layer.

Typical media: HCl (from PVC decomposition), HF (from fluoropolymer decomposition), organic acids (from biodegradable-material degradation products)

5.2.2 Pitting Corrosion

Mechanism: The corrosive medium concentrates attack at surface defects (inclusions, grain boundaries, scratches), forming localized deep pits.

Typical media: chloride-ion media (PVC systems), sulfide-ion media (PPS systems)

Hazard: Pitting pits become stress-concentration sites that may initiate fatigue cracks.

5.2.3 Stress Corrosion Cracking

Mechanism: Under the combined action of tensile stress and a corrosive medium, brittle cracks initiate and propagate in the metal at stress levels far below its yield strength, ultimately leading to brittle fracture.
Triggering conditions: high temperature + corrosive medium + sustained tensile stress (generated by screw torque)

5.3 High-Temperature Degradation

5.3.1 Temper Softening

Mechanism: When alloy steel is exposed to high temperature for prolonged service, martensitic or bainitic structures decompose, reducing hardness and strength.
Critical temperature: It depends on the alloy composition and heat-treatment condition of the material. Nitrided steel begins to soften significantly above 400 °C High-speed tool steel can maintain relatively high hardness at 500–550 °C, while powder metallurgy high-speed steel exhibits superior resistance to temper softening but should still not exceed 560 °C.

5.3.2 Creep

Mechanism: Slow plastic deformation under sustained stress at high temperature.
Typical scenarios: Processing high-performance engineering plastics such as LCP and PEEK (350–420 °C), where screws operate continuously under combined high-torque and high-temperature conditions.

5.4 Fatigue

Mechanism: While rotating, the screw sustains alternating bending and torsional stresses; after long operation, fatigue cracks initiate at stress concentrators and propagate.
Influencing factors: stress amplitude, number of cycles, notch effect (surface defects, root fillets of flights), corrosive environment (corrosion fatigue)
Typical scenarios: Reactive extrusion equipment with a high L/D ratio (L/D > 64), high-throughput production lines for long-term continuous operation, and continuous high-torque processing.

6. Part III: Panorama of Screw Element Material Systems

6.1 Material Grading System

Screw element materials can be classified into four levels according to their wear and corrosion resistance performance.

Figure 3. Classification and Storage of Screw Element Materials by Grade

Tier 1: Nitrided steel

Representative grades: 38CrMoAlA (GB), SACM645 (JIS), 41CrAlMo7(ISO), 1.8509(DIN)

Core process: Gas nitriding or plasma nitriding forms a compound layer consisting of ε-$Fe_{2\text{-}3}N$ and γ′-Fe_4N phases on the steel surface, beneath which lies a diffusion zone containing finely dispersed alloy nitride precipitates such as AlN, CrN, and MoN. This structure significantly improves surface hardness and wear resistance while maintaining good core toughness.

Typical property parameters:

- Surface hardness: HV 900–1100
- Effective nitriding depth: 0.30–0.60 mm
- Core hardness: HRC 28–35 (quenched and tempered)
- Recommended long-term operating temperature: ≤ 400°C; above this temperature, the nitrides gradually coarsen, resulting in a progressive decline in surface hardness and wear resistance.

Advantages:

- High surface hardness and excellent wear resistance

- Good resistance to adhesive wear; suitable for most polymer processing
- Maintains relatively high core toughness and load-carrying capacity.
- Low distortion from heat treatment and good dimensional stability
- Low manufacturing cost and excellent cost-effectiveness.

Limitations:

- Limited nitrided-layer thickness; once worn through, wear resistance drops rapidly
- Limited resistance to strong chemical corrosion; not suitable for long-term processing of halogen-containing, acidic, or strongly corrosive systems
- The compound layer is relatively brittle and, under impact loading or in areas of stress concentration, is prone to microcracking or local spalling.

Typical applications: Suitable for processing general-purpose plastics such as PP, PE, ABS, and PS, as well as low-filled or mild-wear conditions; it is the most common base material for screw elements in cost-sensitive applications.

Tier 2: High-Speed Tool Steel

Representative grades: W6Mo5Cr4V2(GB), SKH51(JIS), HS6-5-2(ISO), 1.3343(DIN)

Core process: Electric-furnace melting combined with electroslag remelting (ESR) yields a clean, homogeneous ingot; after forging, vacuum quenching, and 2–3 high-temperature tempering cycles, the structure consists of tempered martensite as the matrix with dispersed MC (vanadium carbide) and M6C (tungsten/molybdenum carbide) precipitates. This structure combines high hardness, excellent wear resistance, and good red hardness, and is the most widely used integral high-speed tool steel system for twin-screw elements.

Note: High-quality 6542 (W6Mo5Cr4V2) steel used for twin-screw extruder screw elements in China is generally produced using electroslag remelting (ESR) to reduce segregation, refine carbides, and improve microstructural uniformity. ESR is a manufacturing-process upgrade, not a mandatory requirement for 6542 steel.

Typical Property Parameters

- Hardness: HRC 60-64
- Hot hardness:Maintains high hardness and wear resistance at temperatures of 500–600 °C.
- Microstructure: tempered martensite + dispersed MC, M_6C carbides
- Overall performance: wear resistance markedly superior to nitrided steel, while retaining good bulk toughness and impact resistance

Advantages

- High bulk hardness; wear resistance markedly superior to nitrided steel
- MC and M_6C hard carbides confer excellent resistance to abrasive wear, suitable for glass-fiber, mineral-filler, and other medium-to-high wear duty
- Excellent red hardness and tempering stability; stable performance at relatively high processing

temperatures

- Balanced overall performance, achieving a good compromise among wear resistance, toughness, machinability, and cost
- Well-established heat-treatment process; one of the most mature and widely used monolithic high-speed tool steels in the twin-screw extrusion industry.

Limitations

- Limited corrosion resistance; not suitable for long-term processing of strongly corrosive materials such as PVC, fluoropolymers, and high-halogen flame-retardant systems
- Limited by conventional ingot casting, standard 6542 exhibits some carbide segregation; ESR markedly improves structural homogeneity but still falls short of HIP powder-metallurgy steel
- Under severe-wear duty such as very high glass-fiber content or ultra-high mineral filling, service life is generally lower than that of HIP powder-metallurgy high-speed steel

Typical Applications: Suitable for glass-fiber-reinforced engineering plastics, medium-to-high mineral-filled applications, color masterbatch processing, engineering plastics, and most polymer compounding processes, it is currently the most widely used monolithic material choice for twin-screw screw elements. For applications requiring a balance of wear resistance, reliability, and cost-effectiveness, 6542 (M2) remains the most widely used base material in the industry; when wear becomes more severe, it is typically upgraded to an HIP powder-metallurgy high-speed steel system.

Tier 3: Powder-Metallurgy High-Speed Steel

Representative grades: ASP23, ASP30, ASP60 (Erasteel), CPM 10V (Crucible), and the domestic WR series (WR5, WR13, etc.).

Core process: Manufactured using pre-alloyed powder metallurgy (PM) combined with hot isostatic pressing (HIP). Gas atomization, compaction, and HIP densification effectively eliminate carbide segregation in conventional ingot materials, yielding a fine, uniformly dispersed carbide microstructure. After vacuum quenching and multiple tempering cycles, the material combines high hardness, excellent wear resistance, and good dimensional stability, making it a mainstream choice for high-end wear-resistant materials in the twin-screw extrusion industry.

Typical property parameters:

- Hardness: HRC 60–67 (varies by grade)
- Microstructure: tempered martensite + uniformly dispersed hard carbides such as MC,M_6C
- Carbide characteristics: no macro-segregation, homogeneous structure
- Wear resistance: markedly superior to conventional cast/forged high-speed steel and 6542 high-speed steel

Advantages:

- Extremely high and uniform wear resistance

- Excellent structural homogeneity and dimensional stability
- Good resistance to microcrack propagation and long service life
- Suitable for continuous, high-load, high-abrasive-wear conditions.

Limitations:

- High raw-material and manufacturing cost
- Lower bulk toughness than hot-work die steel; relatively sensitive to severe impact loads
- Limited corrosion resistance; unsuitable for strongly corrosive media. Where both wear resistance and corrosion resistance are required, a dedicated PM corrosion-resistant steel or nickel-based alloy should be selected.
- Higher machining difficulty in cutting and grinding; higher requirements for machining equipment and tooling.

Typical applications: Suitable for high glass-fiber reinforcement, high mineral filling, carbon-fiber reinforcement, ceramic fillers, and other high-abrasive-wear operating conditions, as well as continuous industrial production lines requiring long service life, low wear, and stable operation; it is a high-end wear-resistant material system for twin-screw screw elements.

Tier 4: Corrosion-Resistant Alloy Systems

* Unlike the first three levels, which focus mainly on improving wear resistance, the corrosion-resistant alloy system is designed primarily to address chemical corrosion failure mechanisms. Its selection is based not on wear grade, but on the corrosive characteristics of the process medium. In practical engineering applications, corrosion-resistant alloys and powder-metallurgy wear-resistant materials are generally considered parallel options rather than substitutes for each other.

Representative grades: 17-4PH, Hastelloy C-276, Inconel 625, and other corrosion-resistant alloy materials.

Core process: Corrosion-resistant alloys are designed with high chromium, nickel, and molybdenum content. Melting processes such as vacuum induction melting (VIM), electroslag remelting (ESR), or vacuum arc remelting (VAR) improve material cleanliness and microstructural uniformity . After solution treatment, aging, or quenching and tempering, a stable, dense passive film forms on the material surface, effectively resisting attack from acids, alkalis, halogens, and high-temperature corrosive media. Characterized by excellent chemical corrosion resistance, these materials can significantly reduce the risk of pitting corrosion, crevice corrosion, and stress corrosion cracking, making them an important material choice for processing corrosive polymers and chemical reaction systems in the twin-screw extrusion industry.

Typical property parameters:

- Hardness: HRC 35 – 50 (precipitation-hardening stainless steel can reach HRC 40–45;

nickel-based alloys typically HRC 30–45)

- Microstructure: martensitic, austenitic, or precipitation-strengthened microstructures (varies by material system)
- Corrosion resistance: excellent resistance to acids, alkalis, chloride ions, and high-temperature oxidative corrosion
- Overall performance: corrosion resistance markedly superior to ordinary tool steel and high-speed steel; wear resistance varies by material system

Advantages:

- Excellent resistance to acid, alkali, and halogen corrosion
- Effectively suppresses pitting corrosion, crevice corrosion, and stress corrosion cracking; long service life
- High chemical stability reduces metal-ion leaching and product contamination
- Suitable for corrosive polymers and high-cleanliness processing environments; good long-term operating stability

Limitations:

- High raw-material and manufacturing costs
- Bulk wear resistance is usually lower than PM high-speed steel; not suitable for high-abrasive-wear operating conditions.
- Some nickel-based alloys have lower hardness and limited load-bearing capacity
- Higher requirements on machining and heat treatment and higher manufacturing costs; to combine wear and corrosion resistance, a dedicated wear- and corrosion-resistant alloy or surface-strengthening technology is usually required

Typical applications:Suitable for corrosive processing environments such as PVC, fluoropolymers (PVDF, FEP, ETFE), flame-retardant materials, acid/alkali additive systems, reactive extrusion, pharmaceutical hot melt extrusion (HME); it is the main material system for screw elements against chemical corrosion failure in twin-screw extruders.

6.2 Surface Composite Strengthening Systems

Representative processes: Gas nitriding, plasma nitriding, laser cladding, and hardmetal coatings (WC, Cr_3C_2 etc.).

Core Process: Surface composite strengthening systems use advanced manufacturing technologies such as thermochemical treatment, thermal spraying, laser cladding, and hardfacing to build a strengthening layer with high hardness, high wear resistance, or high corrosion resistance on substrates made of high-performance alloy steels, tool steels, or powder-metallurgy materials. This enables synergistic optimization of substrate toughness and surface performance. Compared with using high-alloy materials throughout the entire component, this technology enables targeted strengthening of areas subject to wear, corrosion, or localized high loads, improving material utilization while balancing overall performance. It is an important development direction for high-end twin-screw manufacturing.

Typical Property Parameters:

- Strengthened-layer thickness: about 0.03–3.0 mm (varies by process)
- Surface hardness: HV 900–1800 (WC coating can be higher)
- Bonding: diffusion bonding, metallurgical bonding, or mechanical bonding
- Strengthening characteristics: markedly improves wear resistance, corrosion resistance, and erosion resistance
- Overall performance: local property optimization while retaining substrate strength and toughness

Advantages:

- Markedly increased surface hardness effectively retards abrasive and adhesive wear
- Wear-, corrosion-, or erosion-resistant strengthening solutions can be selected according to the failure mode
- Substrate retains high toughness; overall mechanical properties superior to bulk hard material
- Supports local strengthening and repair/remanufacturing, improving component utilization
- Permits customized design according to operating conditions to meet complex processing needs

Limitations:

- Complex manufacturing process with high demands on equipment and process control
- Applicability varies greatly among strengthening processes; not all operating conditions are suitable
- Coating or cladding thickness is limited; failure may still occur after prolonged severe wear
- Local strengthening zones may involve heat-affected zones or interfacial bonding requirements, demanding high process stability
- Higher cost than conventional heat treatment; should be evaluated jointly with cost-effectiveness and service life

Typical Applications:Suitable for extreme-abrasive-wear operating conditions such as ultra-high glass-fiber reinforcement, carbon-fiber reinforcement, high mineral filling, PCR recyclate, and quartz- or ceramic-filled compounds, as well as complex operating conditions involving both wear and corrosion, such as PVC, fluoropolymers, and flame-retardant materials. Widely used for local strengthening and life extension of high-end twin-screw elements, barrel liners, and other critical wear-prone parts.

7. Part IV: Application Scenario — Material Selection Matrix

The following section systematically cross-maps the ten application scenarios with the material systems. For each scenario, a preferred option, an alternative option, and the key selection rationale are provided. The recommended options also take overall cost-effectiveness into consideration.

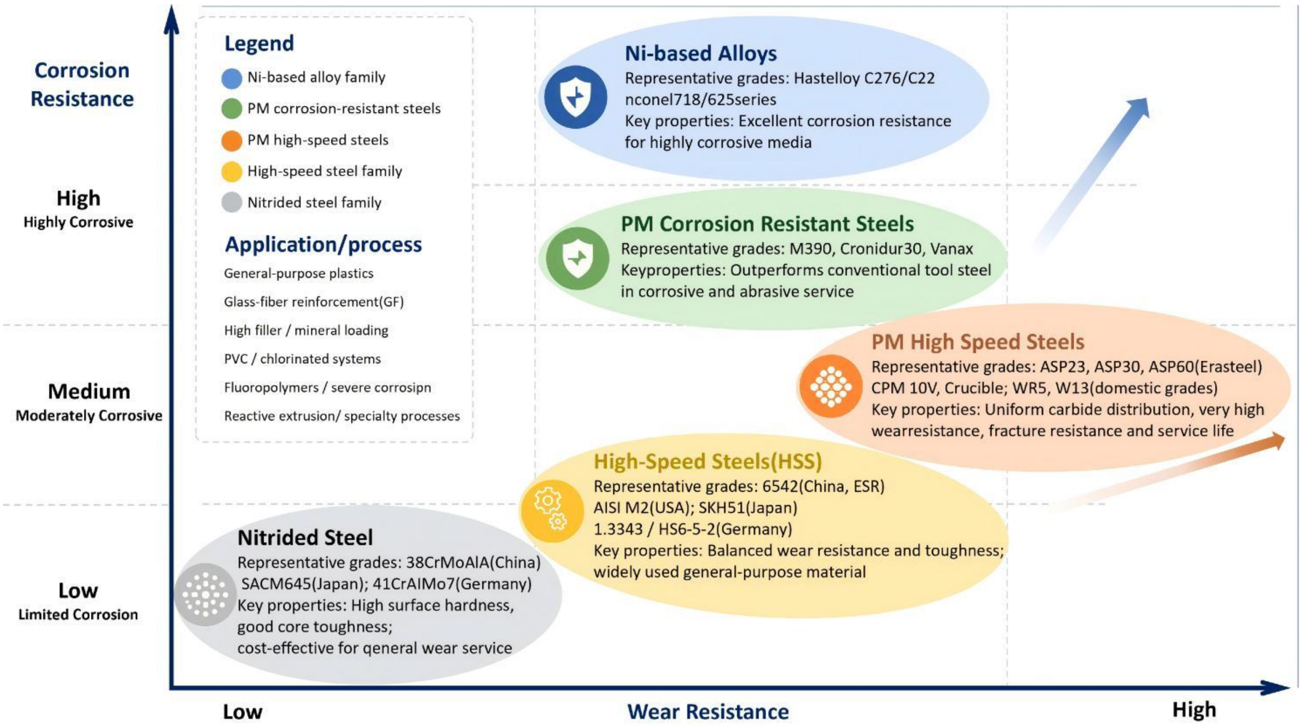

Figure 4. Screw Element Material Selection Map — Wear and Corrosion Resistance Matrix

Scenario 1: General-Purpose Plastics Modification (Filling and Reinforcement)

Dominant failure mode: abrasive wear (mineral fillers) / cutting wear (glass fiber)

Sub-scenario	Filler/fiber content	Recommended material (preferred)	Recommended material (alternative)	Selection rationale
Calcium carbonate/talc filling (General operating conditions)	<30%	Nitrided steel	PM-HIP alloy	Moderate wear; nitrided steel offers the best cost-performance
High mineral filling (calcium carbonate, talc, etc.)	30%–50%	High-speed steel	PM-HIP alloy	Higher filling intensifies wear; surface hardening required
Ultra-high filling (calcium carbonate,	>50%	PM-HIP alloy	—	Extreme abrasive duty;

Sub-scenario	Filler/fiber content	Recommended material (preferred)	Recommended material (alternative)	Selection rationale
barium sulfate, etc.)				tungsten-carbide coating is the best choice
Glass-fiber reinforced	15%–30%	PM-HIP alloy	—	Fiber cutting wear demands extremely high surface hardness
High glass-fiber reinforcement	30%–60%	PM-HIP alloy	Tungsten carbide alloy / Hardmetal Coating	Extremely severe wear at high glass-fiber content
Carbon-fiber reinforced	10%–30%	PM-HIP alloy	—	Carbon fiber is softer than glass fiber but still causes significant wear
Functional masterbatch (high-concentration pigment/additive)	Depends on formulation	High-speed tool steel	PM-HIP alloy	Dispersing pigment agglomerates requires some wear resistance

Engineering note:

- In glass-fiber-reinforced systems, screw configuration design is more critical than material selection; low-shear elements should be used downstream to preserve fiber length, avoiding high-shear kneading blocks
- For ultra-high filling systems (e.g., 60%–80% wood flour in wood-plastic composites), the PM-HIP alloy option should be adopted directly; other options are actually less cost-effective.

Scenario 2: PVC Processing (Cable Compounds)

Dominant failure mode: chemical corrosion (HCl gas)

Sub-scenario	Recommended material (preferred)	Recommended material (alternative)	Selection rationale
Soft PVC	Nitrided steel	High-speed tool steel	Plasticized PVC is processed at lower temperatures, with moderate corrosion severity
High-Filled PVC cable compound	High-speed tool steel	PM-HIP alloy	Abrasive wear dominant
Flame-retardant PVC cable compound	PM-HIP alloy	Nickel-based + tungsten carbide gradient layer	Long-term continuous operation; significant cumulative corrosion effects

High-halogen PVC system	Cobalt-based PM-HIP alloy	Cobalt-based + nickel-based alloy	Cobalt-based alloy offers the best resistance to halogen-containing corrosive media

Engineering note:

- In PVC processing, corrosion resistance should be the first priority, followed by wear resistance.
- Any surface defect on the screw (scratch, pinhole, welding defect) becomes a starting point for HCl corrosion; surface-quality control is therefore critical
- Regularly inspect the screw surface; if signs of pitting or uniform corrosion are detected, repair or replace the screw promptly to prevent corrosion from penetrating into the core.

Scenario 3: Specialty Engineering Plastics Processing

Dominant failure mode: high-temperature temper softening + chemical corrosion (combined failure)

Sub-scenario	Recommended material (preferred)	Recommended material (alternative)	Selection rationale
PPA/PPS	PM-HIP alloy	Nickel-based tungsten carbide alloy	High-temperature strength + resistance to sulfur-containing corrosion
LCP (high temperature, high viscosity)	PM-HIP alloy	Nickel-based tungsten carbide alloy	420°C High temperature and high torque; highest-grade material required
PEEK (ultra-high temperature)	PM-HIP alloy	Cobalt-based PM-HIP alloy	Long-term service at 360–420°C; creep and softening resistance are paramount
Fluoropolymers (PTFE, PVDF, etc.)	Cobalt-based / nickel-based alloys	Tungsten carbide alloy	Extremely severe HF corrosion; superalloy-level corrosion resistance required
High-temperature nylon (glass-fiber-reinforced PPA)	PM-HIP alloy	Tungsten carbide alloy	Combined effects of high temperature, glass-fiber wear, and sulfur-containing corrosion

Engineering note:

- For ultra-high-temperature applications (>350°C), attention should be paid to the screw material's creep-resistance data; many materials that perform well at room temperature rapidly lose strength above 400°C.
- For fluoropolymer processing, the screw maintenance interval should be shortened significantly; a thorough surface inspection is recommended at every shutdown

Scenario 4: TPE/TPV Processing

Dominant failure mode: chemical attack (plasticizing oils, peroxides) + surface adhesion

Sub-scenario	Recommended material (preferred)	Recommended material (alternative)	Selection rationale
SEBS/SBS-based TPE (general)	Nitrided steel	High-speed tool steel	Moderate plasticizing-oil content; moderate chemical attack
High-oil-content TPE (oil loading >40%)	Nickel-based PM-HIP alloy	Nitrided steel	Long-term exposure to high oil content accelerates surface degradation
TPV (dynamic vulcanization)	High-speed tool steel	PM-HIP alloy	Overall tolerance in reactive extrusion environment
TPU	High-speed tool steel	PM-HIP alloy	Moderate TPU processing temperature; weaker chemical attack
Filled/reinforced TPE/TPV	PM-HIP alloy	/	Abrasive wear dominant

Engineering note:

- In TPE processing, screw surface finish affects material adhesion; lower surface roughness reduces material retention
- Consider applying a low-surface-energy coating (e.g., fluorine-containing PVD coating) to the screw surface to reduce adhesion

Scenario 5: Reactive Extrusion and Chemical Modification

Dominant failure mode: chemical corrosion (reaction by-products) + fatigue

Sub-scenario	Recommended material (preferred)	Recommended material (alternative)	Selection rationale
Maleic anhydride grafting (PP-g-MAH, etc.)	Nickel-based PM-HIP alloy	PM-HIP alloy	Moderate corrosion from anhydride vapors
Peroxide-initiated grafting	Nickel-based PM-HIP alloy	Nickel-based tungsten carbide alloy	Oxidative corrosion from peroxide decomposition products
Recycled PET viscosity-building chain extension	PM-HIP alloy	Nickel-based tungsten carbide alloy	Combined corrosion- and wear-resistance requirements
PLA chain-extension modification	High-speed tool steel	PM-HIP alloy	Mild corrosion from lactic-acid degradation products

PAN carbon-fiber precursor (High L/D)	Nickel-based tungsten carbide alloy	PM-HIP alloy	Fatigue life and solvent corrosion of the extra-long screws (L/D > 100)
Bulk polymerization (PA, PLA, etc.)	Nickel-based tungsten carbide alloy	PM-HIP alloy	Highly reactive monomers + long operating cycles

Engineering note:

- In reactive extrusion, shorten the screw inspection interval (recommended every 500–1000 operating hours) and pay special attention to corrosion near the vent zone
- In ultra-high L/D equipment, the screw shaft sustains greater cumulative torsional deformation; screw shaft material selection is likewise important

Scenario 6: Biodegradable Materials Processing

Dominant failure mode: low-grade chemical corrosion (organic acids) + surface-quality requirements

Sub-scenario	Recommended material (preferred)	Recommended material (alternative)	Selection rationale
PLA modification (general)	High-speed tool steel	Nitrided steel	Low corrosiveness of PLA degradation products
High-performance reinforced PLA modification	PM-HIP alloy	High-speed tool steel	Glass-fiber and mineral-filler abrasive wear
PBAT modification	High-speed tool steel	PM-HIP alloy	Similar to PLA; mild corrosion
PLA/PBAT blend	High-speed tool steel	PM-HIP alloy	Slightly longer processing time for the blend system
Starch-based material (TPS)	PM-HIP alloy	High-speed tool steel	Mild corrosion from sugars and organic acids
PHA processing	PM-HIP alloy	—	PHA has poor thermal stability and complex degradation products

Engineering note:

- In biodegradable-material applications, screw surface finish is more important than material grade ; screw elements with surface roughness Ra ≤ 0.4 μm are recommended
- For high-throughput PLA/PBAT production lines, PM-HIP alloy is recommended to achieve longer maintenance intervals

Scenario 7: Food Extrusion Processing

Dominant failure mode: hygiene compliance requirements + cleaning-induced corrosion.

Sub-scenario	Recommended material (preferred)	Recommended material (alternative)	Selection rationale
Extruded snacks / breakfast cereals	Food-grade stainless steel	—	Hygiene compliance + basic corrosion resistance
Texturized vegetable protein (plant-based meat)	Food-grade alloy steel	Food-grade PM-HIP alloy	Moderate wear of high-protein formulations + food safety
Pet food / aquatic feed	Food-grade alloy steel	Stainless steel	Corrosion + wear from animal-protein raw materials such as fish meal
High-acid foods (juice-based, fermented raw materials)	Food-grade PM-HIP alloy	—	Sustained corrosion in an acidic environment
Functional foods (heat-sensitive components such as probiotics)	Food-grade alloy steel	—	Low-temperature processing; compliance is the main material requirement

Engineering note:

- Food-grade screw elements require complete material certificates and food-contact-material compliance documentation
- The acid wash step in CIP cleaning (typically using nitric or phosphoric acid solution) causes non-negligible corrosion of the screw surface; it is recommended to rinse thoroughly with clean water and dry after CIP

Scenario 8: Pharmaceutical Hot Melt Extrusion (HME)

Dominant failure mode: material safety compliance (metal-ion leaching) + cross-contamination

Sub-scenario	Recommended material (preferred)	Recommended material (alternative)	Selection rationale
Solid dispersions (general)	Nickel-based PM-HIP alloy	—	Lowest metal-ion migration + high surface finish
Sustained/controlled-release formulations	Nickel-based PM-HIP alloy	—	Low adhesion + zero contamination
Highly potent APIs (HPAPI)	Nickel-based PM-HIP alloy	—	Zero residue + thorough cleanability

Engineering note:

- Screw-element selection in pharma should be part of equipment qualification (IQ/OQ/PQ) and incorporated into the GMP validation system at the procurement stage
- Select screw suppliers with pharma-industry experience and require complete

material-traceability documentation

- Modular quick-disconnect design not only facilitates cleaning but must also ensure repeatable assembly accuracy; repeated disassembly and reassembly should not cause cumulative fit errors of screw elements

Scenario 9: Recycled Plastics Recovery and Processing

Dominant failure mode: extreme abrasive wear (impurity particles)

Sub-scenario	Recommended material (preferred)	Recommended material (alternative)	Selection rationale
PET flake recycling and pelletizing	PM-HIP alloy	Nickel-based PM-HIP alloy	Combined impurity-induced wear + water-vapor corrosion
PE/PP film recycling	High-speed tool steel	PM-HIP alloy	Severe wear from mud and sand impurities
Waste Electrical & Electronic Plastics Recycling	PM-HIP alloy	—	Combined conditions of metal impurities + oil contamination + mixed plastics
Engineering-plastics recycling (PA, PC, etc.)	PM-HIP alloy	—	Combined high temperature- and wear-resistance requirements

Engineering note:

- In recyclate processing, material pre-treatment (magnetic separation, air classification, screening, washing) is the most effective means of reducing screw wear; reducing contaminants at the source is more economical than upgrading the material grade
- Install a strong magnetic separator (>10,000 gauss) before the feed port to capture ferromagnetic metal impurities
- Screw wear should be measured periodically (recommended every 500 operating hours); when flight outer-diameter wear exceeds 0.3 mm, the screw should be promptly replaced or repaired

Scenario 10: Powder Coatings and Thermoset/Magnetic Materials

Dominant failure mode: extreme abrasive wear (magnetic powder) + cured deposits

Sub-scenario	Recommended material (preferred)	Recommended material (alternative)	Selection rationale
Powder coatings (general)	High-speed tool steel	PM-HIP alloy	Pigment/filler wear + prevention of resin adhesion and curing
Phenolic molding compound (bakelite powder)	PM-HIP alloy	—	Cured deposits + filler wear

Magnetic plastics (NdFeB-based)	Tungsten carbide alloy	PM-HIP alloy	One of the most extreme wear conditions in the industry
Magnetic plastics (ferrite-based)	PM-HIP alloy	—	Ferrite is softer than NdFeB but still causes significant wear.

Engineering note:

- Screw life in magnetic-plastics processing is the shortest among all scenarios; ease of screw replacement and coating repairability should be considered at the equipment design stage
- In powder-coating processing, a low-surface-energy coating may be applied on the screw surface to reduce resin adhesion and pre-curing

8. Part V: Selection Decision Process and Methodology

8.1 Four-Step Decision Method

When selecting materials for a specific application, the following four-step decision process is recommended:

Step 1: Identify the dominant failure mode

Ask yourself: under my material and process conditions, how is the screw most likely to cause screw failure?

Material/Process Category	Dominant Failure Mode / Key Considerations
Mineral Fillers, Glass Fibers, and Impurities	Wear-Dominated
PVC, Fluorine-/Sulfur-Containing Materials, and Strong Acid/Base Additives	Corrosion-Dominated
High-Temperature Engineering Plastics (>300°C)	Thermal Degradation-Dominated
Recyclate, high filling, magnetic powder	Extreme wear
PVC + mineral fillers	Combined Corrosion + Wear
Food, Pharmaceutical	Compliance Requirements + Surface Quality
Reactive Extrusion (Extended Continuous Operation)	Chemical Corrosion + Fatigue

Step 2: Assess the severity of the operating condition

Severity	Typical conditions	Material-level guidance
Mild	General-purpose plastics, low filler loading(<20%), no corrosion	Nitrided steel
Moderate	Engineering plastics, medium filler loading (20%–40%), mild corrosion	High-Speed Tool Steel

Strong	High filler loading (>40%), glass-fiber reinforcement, moderate corrosion, magnetic plastics	PM-HIP alloy or surface strengthening
Severe	Extreme Wear, Severe Corrosion, High-Temperature Conditions,	Corrosion-Resistant PM-HIP Alloy System + Surface Strengthening
Extreme	Fluoropolymers, Highly Potent APIs (HPAPIs)	Corrosion-Resistant Alloy System + Surface Strengthening

Step 3: Co-Optimize Material Selection with Screw Configuration Design

Material selection is not an isolated decision. Screw configuration design can either reduce or increase the stress and wear load on the material:

- Reduce shear intensity (smaller kneading-block stagger angle, higher proportion of conveying sections) → lower temperature rise and wear → material grade can be moderately lowered
- Add reverse elements to build pressure → increase fill level → intensify wear and corrosion → a higher material grade is required.
- Increase the proportion of toothed-disc elements → promote elongational/lamellar flow while relatively reducing shear intensity → thereby reducing fiber breakage and surface cutting.

Step 4: Calculate the life-cycle cost

Life-cycle cost = initial procurement cost + installation/commissioning cost + maintenance/repair cost + downtime loss + scrap loss

Where:

- Initial procurement cost: surface strengthening > PM-HIP alloy > high-speed steel > nitrided steel
- Maintenance/repair cost: higher-grade materials have longer replacement intervals
- Downtime loss: on high-throughput lines, hourly downtime loss can reach thousands to tens of thousands of yuan
- Scrap loss: screw wear increases clearance, leading to fluctuations in product quality.

Core principle: For high-throughput continuous lines, the life-cycle cost of higher-grade materials is usually lower than that of lower-grade materials. For R&D equipment and low-volume, multi-variety production, mid-grade materials offer greater flexibility and better cost-effectiveness.

8.2 Common Selection Pitfalls

Misconception	Correct understanding
"Nitrided steel is fine for all	Nitrided steel is suitable for mild duty; it is inadequate for highly filled and

scenarios"	strongly corrosive conditions.
"The more expensive, the better"	Material selection should match the operating conditions—pharmaceutical applications require compliance rather than extreme wear resistance.
"Replace the screw only after it fails"	Screw wear causes product-quality fluctuation; replace proactively before failure.
"Material selection is the supplier’s concern"	The user knows their material and operating conditions best and takes the lead in defining material-selection requirements.
"All elements on one screw should use the same material"	Different materials should be selected per section according to differing failure modes (e.g., PM-HIP alloy in wear zones, nickel-based alloy in corrosion zones)

9. Part VI: Engineering Case Studies

Case 1: 40% Glass-Fiber-Reinforced PA66 Production Line - PM-HIP Powder Metallurgy Steel Extends Wear Life

Application Background

Glass-fiber-reinforced PA66(PA66+GF40) is a typical high-performance engineering plastics processing system, widely used in automotive parts, electrical and electronic applications , and industrial structural components.

Because glass fibers have high hardness and rigidity, they cause continuous abrasive wear on screw elements during twin-screw extrusion, particularly in the following areas:

- Kneading-block zones;
- Toothed-disc zones;
- High-shear mixing zones.

For 24-hour continuous production lines, the wear resistance of screw elements directly affects product stability and equipment operating cost.

Operating Conditions

- Material processed: 40% glass-fiber-reinforced PA66;
- Equipment type: co-rotating twin-screw extruder;
- Screw L/D: 48;
- Screw speed: 400 rpm;
- Throughput: 800 kg/h;
- Operation mode: 24-hour continuous production.

Initial Material Scheme — Screw element material: 38CrMoAlA nitrided steel

38CrMoAlA nitrided steel, with its mature processing technology and cost-effectiveness, is widely used in engineering-plastics modification.

Its advantages:

- High hardness of the nitrided layer;
- Low cost;
- Stable overall performance.

Its limitations are:

- Limited nitrided-layer thickness;
- The surface hardened layer is gradually worn away after prolonged exposure to glass-fiber abrasion
- High-shear zones are prone to accelerated wear.

Operating Problems

After about 800 hours of continuous operation, the following were found:

- Obvious wear in the high-shear kneading-block zones;
- Local screw-flight height reduction of about 0.5 mm;
- Reduced mixing efficiency;
- Increased fluctuations in product properties.

Failure analysis showed:

Wear was concentrated in high-shear, high-filler-contact zones, while ordinary conveying zones remained in good condition.

Optimization Scheme — A zoned, graded material-selection strategy was adopted:

High-wear zones, such as kneading blocks and toothed discs, were upgraded to:

- PM-HIP powder-metallurgy high-speed steel
- Alloy steel can continue to be used in ordinary conveying zones. Since filler-induced wear is relatively low in the conveying section, a lower-cost steel grade may be considered for cost-effectiveness.

PM-HIP powder-metallurgy high-speed steel offers:

- High wear resistance;
- Homogeneous carbide structure;
- Good high-temperature hardness retention;
- Better suited for long-term operation with glass-fiber-reinforced materials.

Results

After optimization:

- Screw maintenance interval increased from about 800 hours to over 4,000 hours;
- Unplanned downtime was significantly reduced;
- Improved product quality stability.

Technical Summary

For glass-fiber-reinforced engineering-plastics processing, screw failure usually concentrates in high-shear mixing zones. Compared with upgrading the entire screw to high-grade material:

" PM-HIP powder metallurgy high-speed steel in critical zones + cost-effective materials in ordinary zones"

This achieves better overall cost control while extending service life.

Case 2: Rigid-PVC Production Line - Corrosion-Resistant Alloy Strengthening Solves Pitting Corrosion

Application Background

During rigid-PVC (uPVC) processing, the material's poor thermal stability tends to produce trace acidic degradation products such as HCl under high-temperature shear.

These corrosive media usually concentrate in:

- Venting zones;
- High-residence-time zones;
- Melt-pressure-variation zones.

Thus, in PVC processing, the screw material must be both wear-resistant and corrosion-resistant.

Operating Conditions

- Material processed: rigid PVC (uPVC);
- Equipment type: twin-screw extruder;
- Processing temperature: about 175°C;
- Formulation: contains organotin stabilizer;
- Production mode: continuous operation.

Initial Material Scheme — High-speed tool steel screw elements

This scheme meets general PVC processing needs, but over prolonged operation may pose a corrosion risk when exposed to acidic degradation products.

Operating Problems

After about 9 months of operation, the following were found:

- Obvious pitting near the vent;
- Local corrosion-pit depth reaching about 0.3 mm;
- Reduced surface integrity.

Failure analysis:

Corrosion occurred mainly in the venting zone.

Cause:

Acidic volatiles released during PVC processing accumulate in the venting zone and remain in prolonged contact with the metal surface, forming localized corrosion.

Optimization Scheme — A local corrosion-resistant strengthening scheme was adopted:

- Corrosion-sensitive zones before and after the vent;
- Strengthened by nickel-based corrosion-resistant alloy cladding;
- The remaining zones retained the original alloy-steel structure.

By precisely strengthening the corrosion-risk zones, this scheme avoids applying costly corrosion-resistant material throughout the entire screw.

Results

After optimization:

- 24 months of continuous operation;
- Stable surface condition of the strengthened zones upon inspection;
- No significant corrosion was observed.

Meanwhile:

- Retrofit cost was about a fraction of a full upgrade;
- Achieving a balance between service-life extension and cost control.

Technical Summary

Corrosion in PVC processing usually has clear zonal characteristics.

Compared with using corrosion-resistant material for the entire screw:

Targeted corrosion-resistant strengthening of the corrosion-sensitive zones is a more economical and effective engineering solution.

Case 3: PET Flake Recycling and Pelletizing Line - Synergistic Optimization of Material Upgrading and Pre-treatment

Application Background

PET flake recycling and pelletizing is an important application in the circular economy.

Because recycled feedstock comes from diverse sources, it typically contains:

- Label residues;
- Sand and stone impurities;
- Metal contaminants;
- Wash residues.

Thus, during rPET processing, screw elements simultaneously face:

- Abrasive wear;
- High-temperature operation;
- Hydrolytic degradation;
- Chemical corrosion.

Operating Conditions

- Material processed: recycled PET flakes;
- Equipment type: twin-screw pelletizing system;
- Screw L/D: 40;
- Throughput: 1500 kg/h;
- Operation mode: 24-hour continuous;
- Feedstock characteristics: contains small amounts of metal and sand/stone impurities

Initial Material Scheme — High-speed tool steel screw elements + upstream magnetic separation system

This scheme meets general recycling needs, but its wear resistance is insufficient for complex recycled feedstock.

Operating Problems

After about 600 hours of operation, the following were found:

- Increased wear in the feeding zone;
- Obvious wear of screw flights in the plasticizing zone;
- Reduced equipment operating stability.

Failure analysis:

Main Sources of Wear:

- Hard impurities in the recyclate;
- Continuous abrasion during high-temperature PET processing;
- Surface fatigue from prolonged operation

Optimization Scheme — A comprehensive optimization scheme was adopted:

Step 1: Optimize feedstock pre-treatment

Strengthen the following:

- Magnetic separation;
- Screening;
- Impurity control.

Reduce the number of hard particles entering the extrusion system.

Step 2: Upgrade screw element materials

For high-wear zones:

Upgrade to: powder-metallurgy high-speed tool steel screw elements

- High wear resistance;
- Good toughness balance;
- Suitable for long-term continuous recycling operations.

For highly corrosive scenarios, a further upgrade to:

Corrosion-resistant alloy material system.

Results

After optimization:

- Maintenance interval increased from about 600 hours to over 3500 hours;
- Improved equipment operating stability;
- Markedly lower overall maintenance cost.

Technical Summary

Extending service life in recycled-plastics processing does not rely solely on upgrading the material.

In practice, material upgrades generally contribute more to service-life extension, while improved pretreatment is often more cost-effective. The best overall economic performance can be achieved through coordinated optimization of raw-material control, appropriate material selection, and targeted reinforcement of critical areas.

For more case references, visit https://www.lesunscrew.com/knowledge/

10. Part VII: Trends and Outlook

10.1 Materials Technology Trends

Composite material design is becoming increasingly widespread. A single material is increasingly unable to meet the multiple demands of complex operating conditions. Solutions such as tungsten carbide + nickel-based alloys and PM-HIP are becoming increasingly mainstream. By using different material compositions at different depths, these solutions achieve an optimal combination of surface wear/corrosion resistance and core toughness/strength.

The degree of steel customization is increasing. Steel suppliers are developing dedicated alloy formulations for specific application scenarios - for example, low-nickel corrosion-resistant alloys for PVC processing and ultrafine tungsten-carbide coatings for highly glass-fiber-filled materials.

Additive manufacturing is beginning to gain traction. Metal additive-manufacturing technologies, such as selective laser cladding, are being explored for manufacturing complex-shaped screw elements, especially internal cooling channels and profiled mixing structures that are difficult to realize by conventional processes.

10.2 Intelligentization Trends

Digital twins and life prediction.

Based on fatigue-property data of the screw material, operating-condition data (torque, temperature, throughput), and wear models, a digital-twin model of the screw elements is built to enable real-time remaining-service-life prediction and preventive-maintenance scheduling.

Online monitoring technology.

Advances in barrel vibration sensors, acoustic-emission sensors, and online melt-quality monitoring technologies (e.g.near-infrared spectroscopy) make indirect monitoring of screw wear state possible.

10.3 Sustainability Trends

Green alloy development. Alloy formulations that reduce or replace scarce metals (e.g.,, cobalt, nickel, tungsten) are under development, aiming to maintain performance while reducing dependence on strategic mineral resources.

11. Appendix

Appendix A: Glossary

Term	Definition
Lead	Axial distance advanced per full screw revolution
Stagger Angle	Deflection angle between adjacent discs in a kneading block
L/D Ratio	Ratio of effective screw length to screw diameter
Specific Energy	Energy consumed per kilogram of material processed (kWh/kg)
Specific Torque	Torque sustained per unit screw volume (Nm/cm^3)
PM-HIP	Powder metallurgy hot isostatic pressing process
PTA	Plasma transferred arc hardfacing
PVD	Physical vapor deposition
HVOF	High-velocity oxy-fuel spraying
CIP	Clean-in-place
GMP	Good Manufacturing Practice
HME	Hot melt extrusion
API	Active pharmaceutical ingredient

Appendix B: References and Source Notes

The knowledge base of this white paper is drawn from a comprehensive analysis of the following categories of sources :

1. Academic literature: Classic textbooks and scholarly journals in polymer processing
2. Materials-science fundamentals: Standard references in physical metallurgy, tribology, and corrosion engineering
3. Industry practical experience: Widely accepted engineering rules of thumb in polymer processing and equipment maintenance

About Nanjing Lesun

Nanjing Lesun Screw Co., Ltd. specializes in the R&D and manufacturing of core components for twin-screw extruders, including screw elements, screw shaftss, and barrels.
Drawing on years of application experience in plastics modification, LESUN continues to focus on how different material systems, additive combinations, and processing environments affect screw performance, and is committed to providing customers with more reliable material-selection and engineering solutions.
This guide is Lesun Screw's technical summary of screw-element material-selection methodology for twin-screw extruders, intended to share industry knowledge and promote more scientific engineering practice.

Editor's Note

This white paper is Lesun Screw's first systematic compilation and summary of screw element material selection for twin-screw extruders. In preparing this white paper, we drew on long-term industry experience, material-property analysis, and professional literature from China and abroad to summarize and discuss the characteristics, applicable operating conditions, and material-selection rationale of different material systems.

Because screw-element material selection involves materials science, mechanical design, processing technology, and specific application environments, many complex variables remain in practical application. The views and recommendations in this white paper are intended to provide industry engineers with a reference for material selection and a decision-making framework, and do not replace professional engineering analysis for specific operating conditions.

Given the continuous development of industry technology and the differences among companies in equipment structure, processing conditions, and application systems, the content inevitably has certain limitations. We sincerely welcome industry experts, engineers, and readers to provide comments and suggestions on any inaccuracies or areas for improvement, so that we can jointly advance the development of material application technology in the twin-screw extrusion industry.

Lesun Screw will continue to follow technological developments in the industry and optimize and update the content based on new practical experience and research findings.

Disclaimer:

The content of this guide is provided for technical reference only. Screw material selection should be comprehensively evaluated based on specific processing conditions, material formulations, equipment configuration, and production requirements.

Actual performance may vary under different application environments; final material selection should be based on analysis of the specific operating conditions and technical validation.

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