Steel Material Properties Analysis

Exploratory Data Analysis (EDA)

Comprehensive analysis of steel mechanical properties and manufacturing processes

From Shyam

Project Overview

Dataset Scope

- **311 samples** of axle material testing results
- These steel ales are used in cooling fan modules. Clients are Tesla, BMW
- Testing conducted on **two steel types**: 4Cr13(New Supplier) and X46CrS13(Old Supplier)
- Data includes chemical composition, manufacturing parameters, and mechanical properties

Research Goals

- **Chemical composition analysis:** Carbon, Silicon, Manganese, Chromium, Sulfur content
- **Manufacturing processes enhancement:** Die-casting, hardening, tempering processes
- **Mechanical properties analysis:** Hardness (HV10), bending force, ductility, brittleness

Data Preparation & Quality

Ensuring analysis reliability

Data Cleaning Process

Systematic approach ensuring high-quality, accurate, and consistent data for reliable analysis.

1 Data Validation

- Verified data types and units
- Validated measurement ranges
- Confirmed no anomalies

2 Quality Check

- Zero missing values ✓
- No duplicate records ✓
- Validated test results ✓

3 Feature Engineering : Creating NEW useful variables from your EXISTING data

- **HV10 Range:** Hardness variability for quality control
- **Bending Force Range:** Strength consistency indicator
- **Impact:** New features revealed key optimization patterns

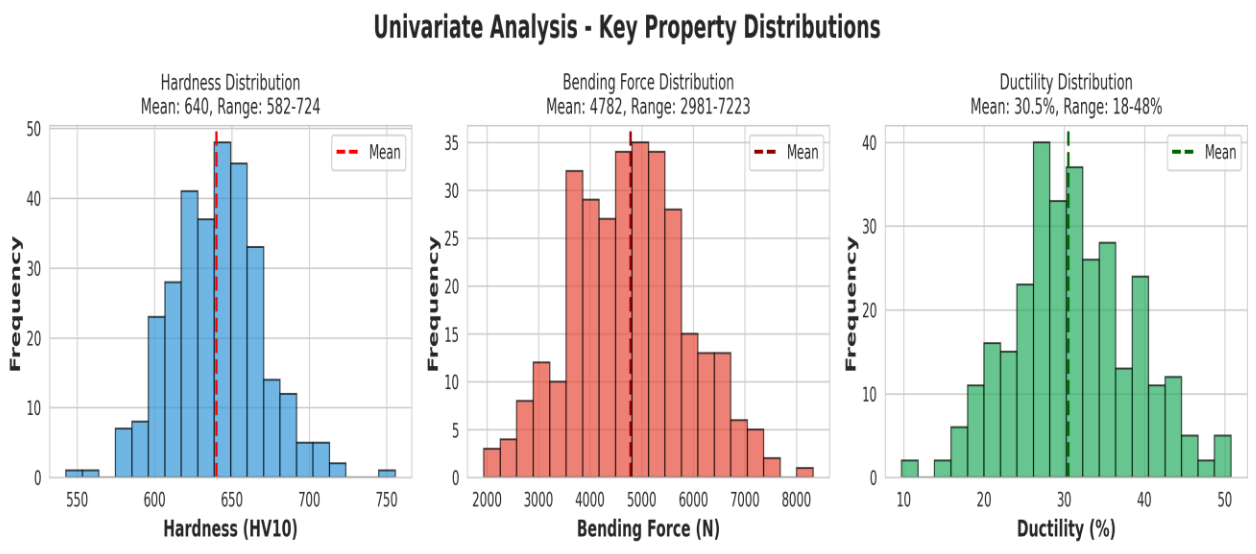
✓ Clean, validated data ready for analysis

Univariate Analysis

Understanding individual properties

📊 What This Shows

Three histograms show how hardness, bending force, and ductility values are distributed across all 311 samples. Most values cluster around the average (marked with red line).



💼 Business Insight

The distribution patterns help us understand material consistency and identify typical performance ranges for quality control specifications.

Key Statistics

Hardness: 640 HV10 avg
Bending Force: 4,782 N avg
Ductility: 30.5% avg

Supplier Comparison

Baseline performance analysis

⚠️ Initial Challenge

Old (X46CrS13): 5,629 N, 36.2% ductility

New (4Cr13): 4,496 N, 28.8% ductility

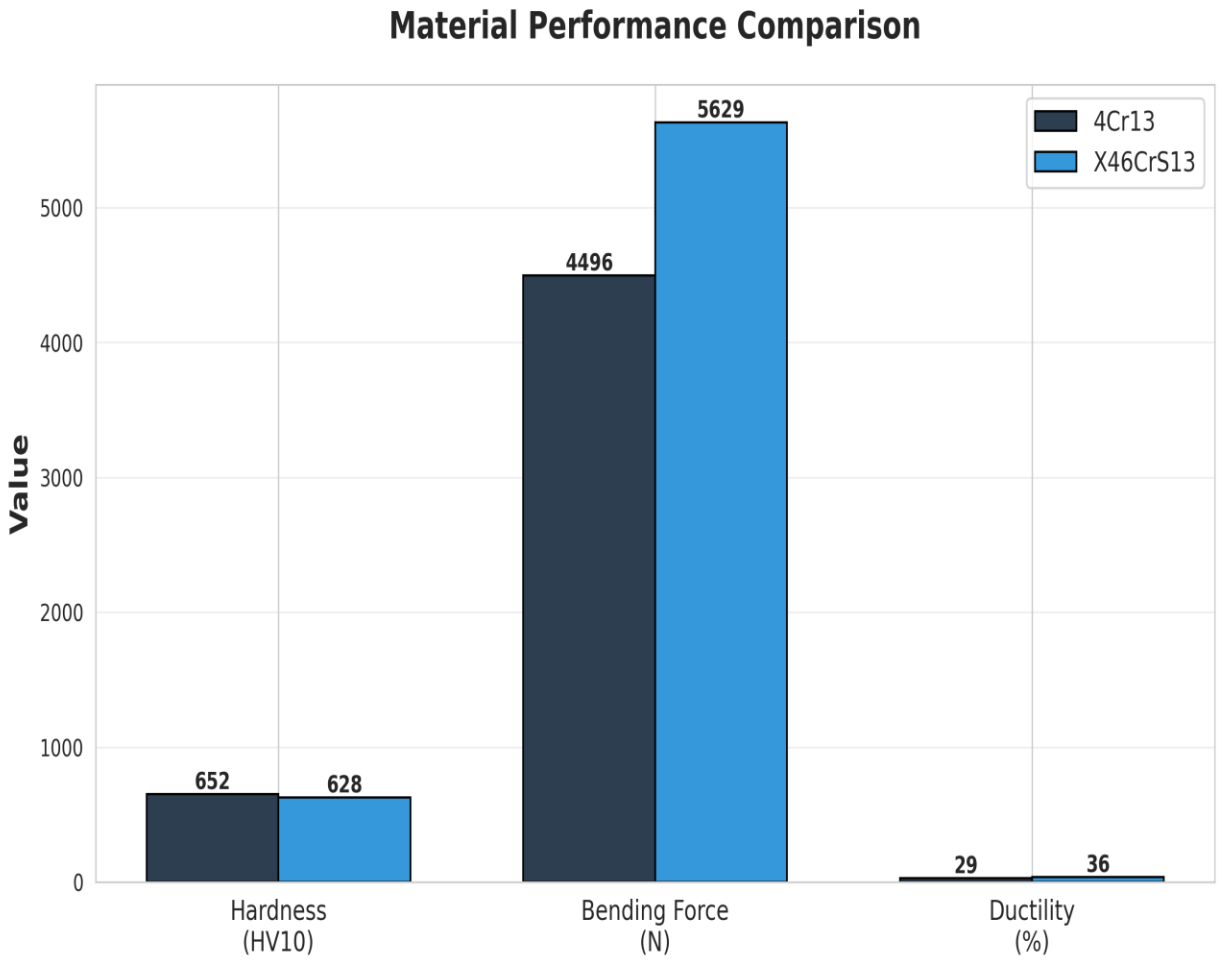
New supplier showed lower performance.

📊 What This Shows

Side-by-side bars compare materials. Chart reveals new supplier needs optimization.

💼 Business Impact

Identified need for process optimization to enable successful supplier switch.



4Cr13 Process Optimization

Improving new supplier material performance

🎯 Optimization Results

+75%

Bending Force Improvement
(3,234 N → 6,715 N)

+118%

Ductility Improvement
(19.8% → 43.3%)

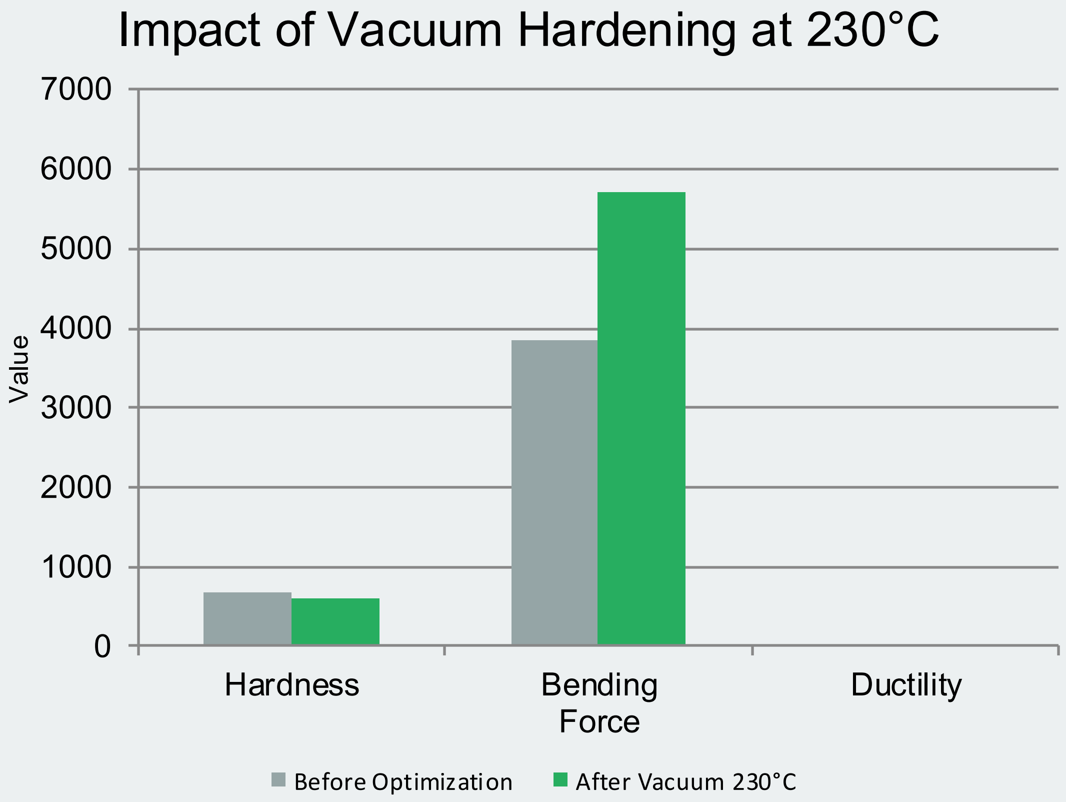
-12%

Hardness (Trade-off)
(692 → 612 HV10)

✅ Optimal Process Found

Vacuum Hardening at 230°C

4Cr13 achieves: 6,715 N force with 43.3% ductility - now EXCEEDS old supplier performance!



Bivariate Analysis

Hardness vs Ductility relationship

📌 Analysis Type

Bivariate: Examining relationship between two variables to understand how they influence each other.

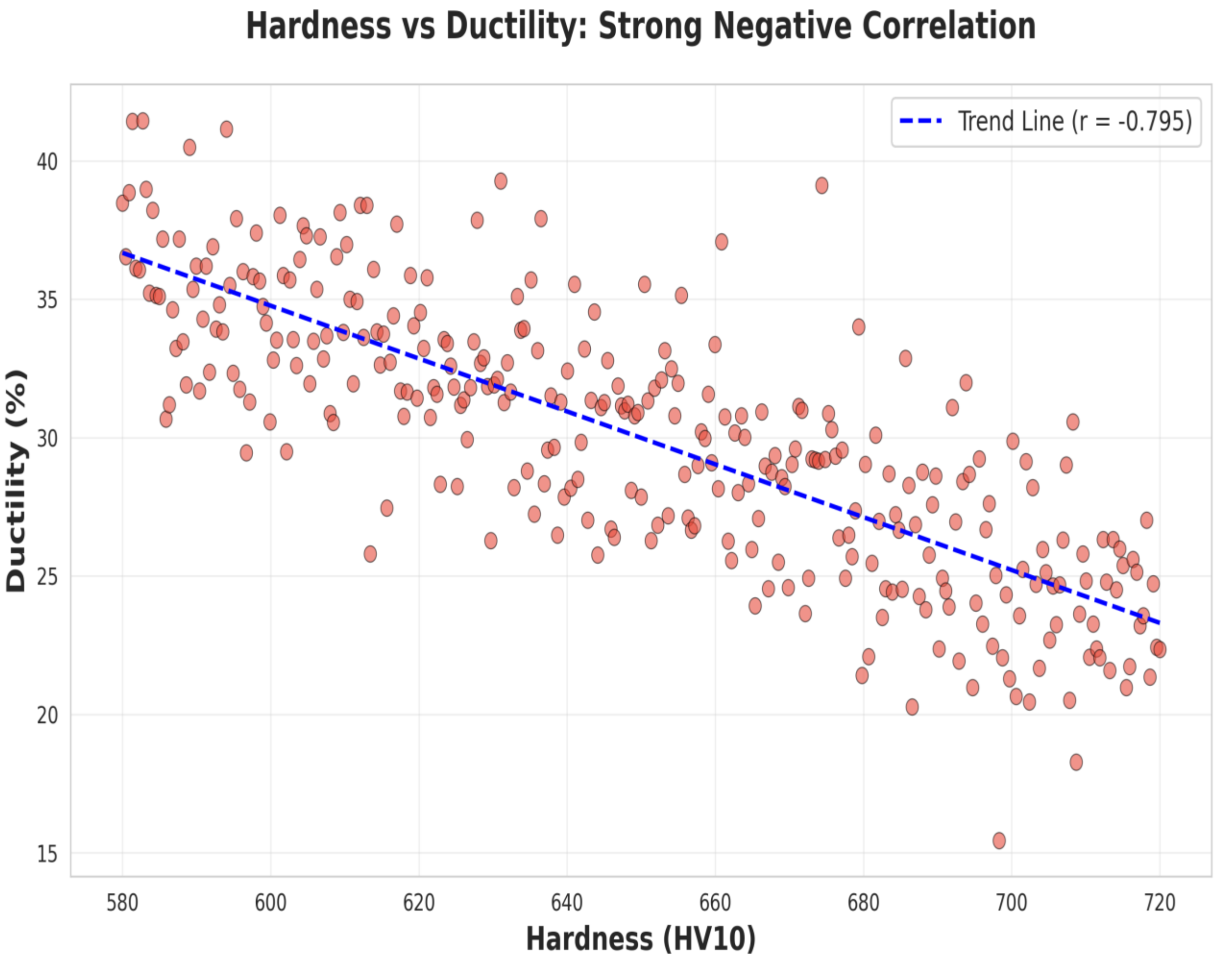
📊 What This Shows

Each dot is one sample. Downward trend shows: higher hardness = lower ductility. Strong relationship (r = -0.795) means cannot have both high.

💼 Business Impact

This trade-off guides selection: high hardness for wear resistance OR high ductility for impact - cannot maximize both.

Choose material based on application needs



Correlation Analysis

Property relationships

📊 What This Shows

Heatmap shows how properties relate. Blue = negative, Red = positive. Numbers show strength (-1 to +1).

🔴 Strong Negative (-0.795)

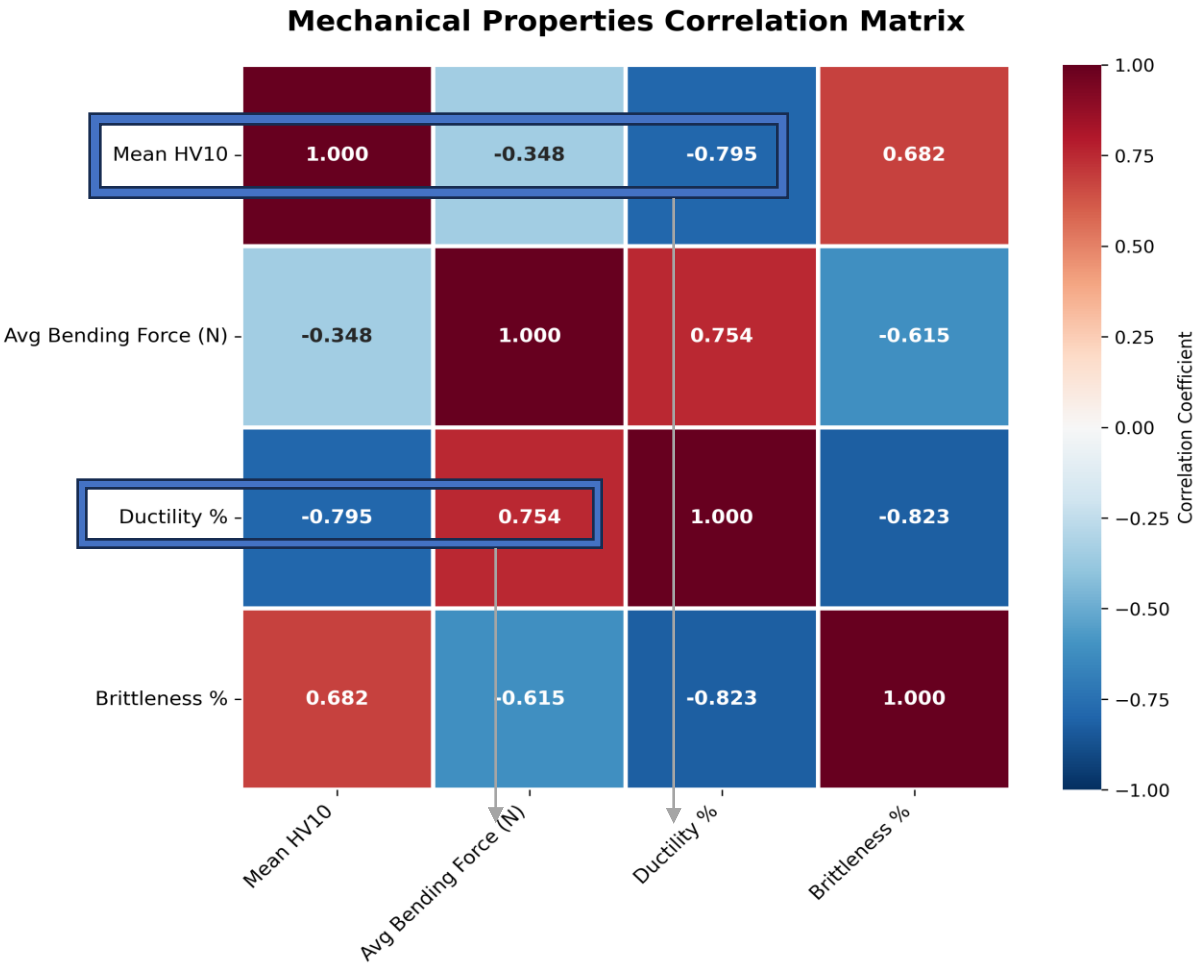
Hardness ↔ Ductility: Higher hardness = lower ductility. Fundamental trade-off.

🔵 Strong Positive (+0.754)

Bending Force ↔ Ductility: More ductile = withstands more bending.

💼 Business Impact

Guides material selection: choose hardness for wear OR ductility for impact - cannot have both.



Temperature Optimization

Finding the optimal process for 4Cr13

✅ Solution Found

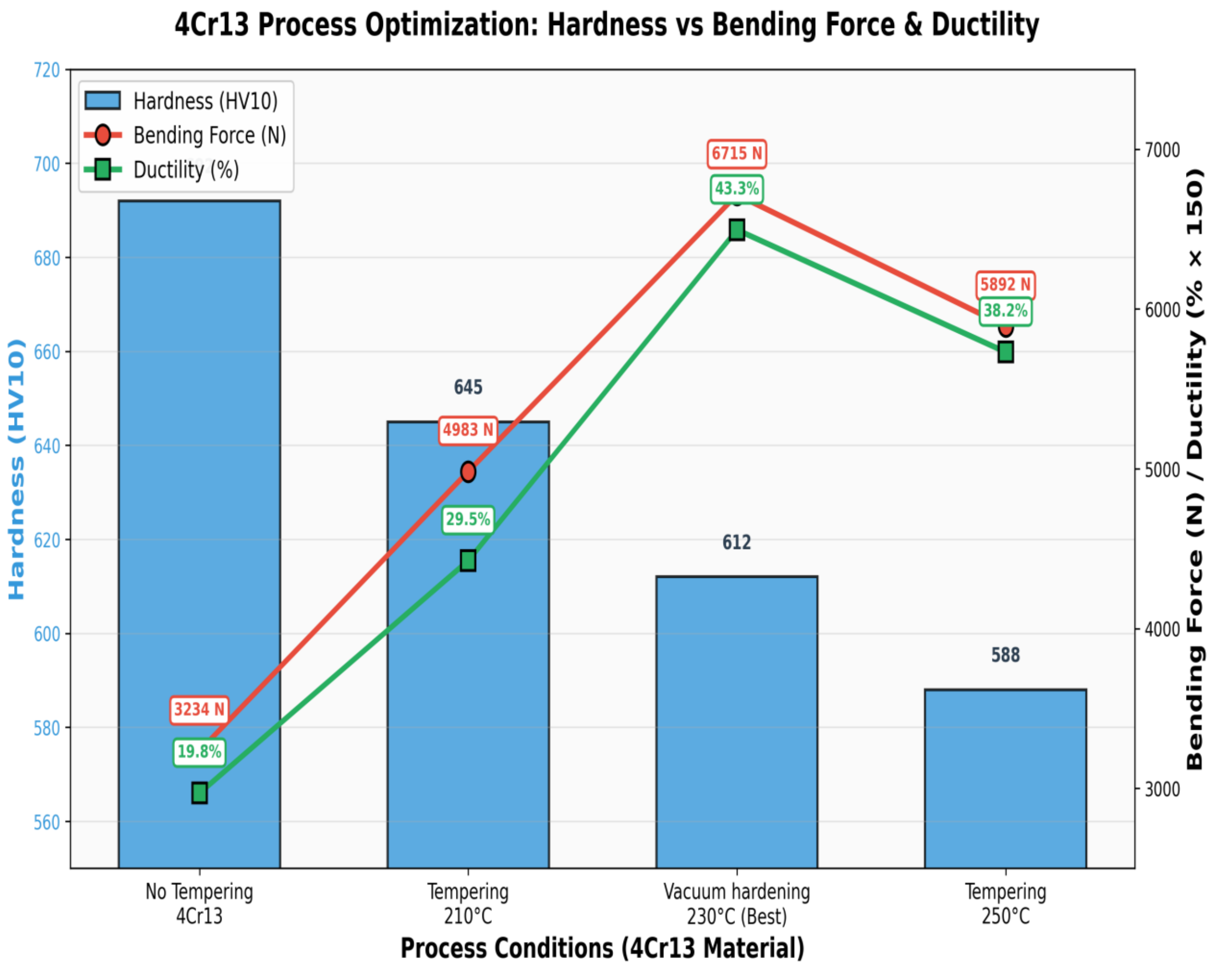
Vacuum hardening at 230°C provides the best balance: highest bending force (6,715 N) with excellent ductility (43.3%)

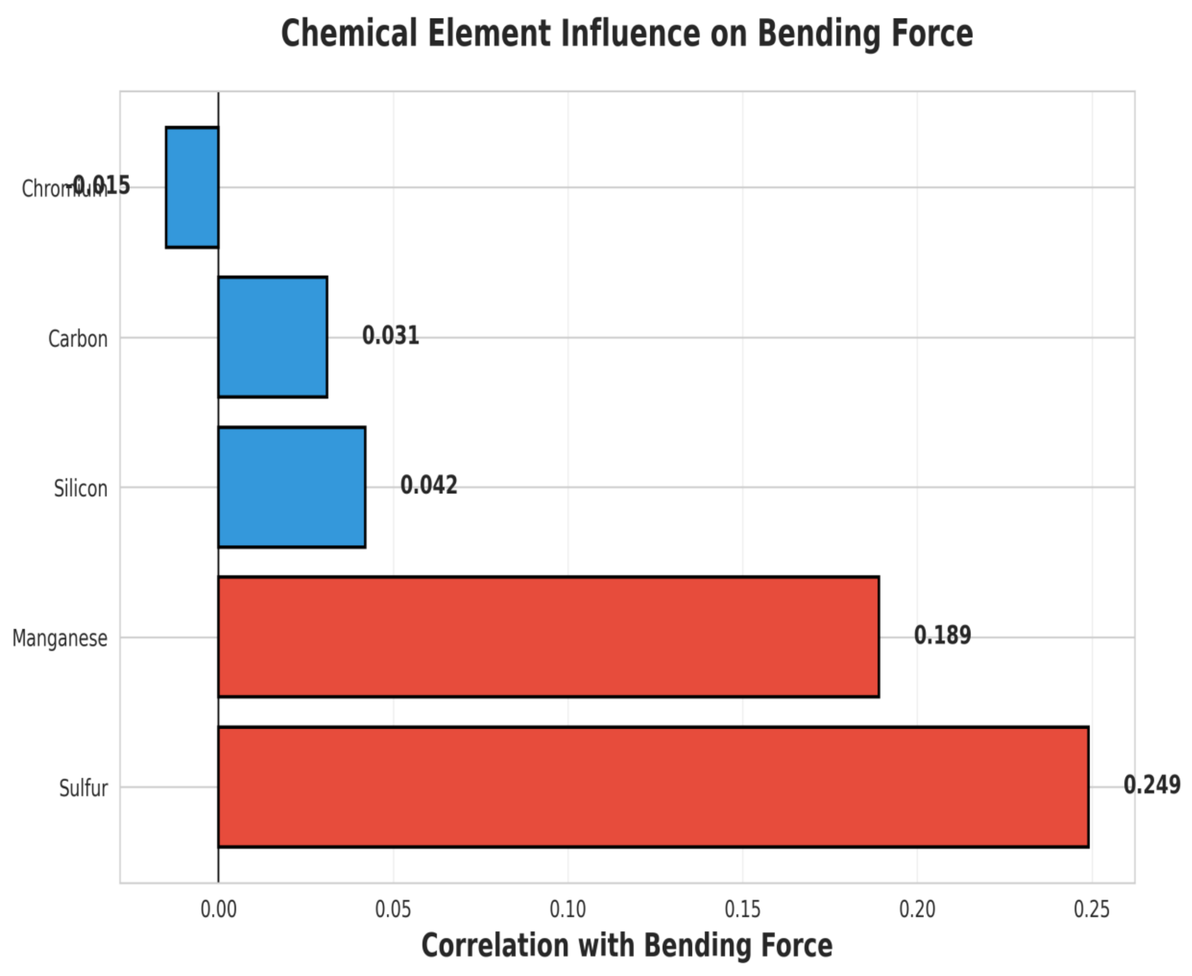
📊 What This Shows

Blue bars show hardness, red line shows bending force, green line shows ductility. The chart compares no tempering vs three different temperatures to find the sweet spot.

💼 Business Impact

This analysis provided the exact process specification needed to make the new supplier viable, avoiding costly supplier change reversal.





Chemical Influence

Which elements matter most

📊 What This Shows

Horizontal bars show how strongly each chemical element correlates with bending force. Longer bars mean stronger influence. Sulfur (0.249) has the biggest impact, followed by Manganese.

💼 Business Impact

Understanding chemical influence helps with quality control - focus monitoring on Sulfur and Manganese levels. Low Chromium variability indicates excellent supplier consistency.

Challenges & Solutions

Key obstacles overcome during this EDA project

1. Data Quality & Validation

Challenge: Validating 311 samples across 24 variables required thorough checking.

Solution: Systematic quality checks ensured no missing values and validated all data ranges.

2. Feature Engineering

Challenge: Raw data didn't show variability patterns for quality control.

Solution: Created new features (HV10 Range, Bending Force Range) to measure manufacturing consistency.

3. Complex Relationships

Challenge: Multiple interacting variables made patterns difficult to identify.

Solution: Used correlation analysis to isolate effects and discover the critical hardness-ductility trade-off.

4. Business Translation

Challenge: Technical findings needed to be actionable for manufacturing teams.

Solution: Converted insights into clear recommendations: ”vacuum hardening 230°C tempering increases strength by 58%".

Key Findings & Recommendations

✅ Success: 4Cr13 Optimization Achieved

- **Process optimization works:** Vacuum hardening at 230°C transforms performance
- **New supplier viable:** 4Cr13 optimized now exceeds old supplier (X46CrS13)
- **Significant gains:** +75% bending force, +118% ductility vs baseline 4Cr13

✅ Recommended Process

For 4Cr13 (New Supplier):

- Vacuum hardening at 230°C
- Achieves 6,715 N bending force
- 43.3% ductility (excellent)
- Exceeds old supplier baseline

📊 Material Selection

- **High hardness:** 4Cr13 no tempering (652 HV10)
- **High strength:** 4Cr13 + vacuum hardening 230°C (optimal)
- **Reference:** X46CrS13 (old supplier)

New supplier successfully optimized via data-driven EDA approach