Evaluation of Quenching-Tempering Effects on AISI 1018 and AISI 1045 Steels

Landing Gear Component Reliability and Fatigue Resistance

1. Introduction

Landing-gear components in modern aircraft are subjected to repeated high-cycle fatigue, impact loading, and corrosive environments. Premature failure of these critical parts carries severe safety and operational consequences. Heat treatment—specifically quenching and tempering—remains the most effective metallurgical method to tailor the strength–toughness balance of low- and medium-carbon steels. This report examines the influence of tempering soak duration on the Rockwell HRF hardness of AISI 1018 (low-carbon) and AISI 1045 (medium-carbon) steels. The tempering treatments were conducted at 240 °C and 285 °C, respectively, following a standard quench from the austenitizing temperature. The goal is to identify treatment windows that maximize hardness while preserving the toughness required to resist fatigue and high-impact failure.

2. Objectives

The specific objectives of this evaluation were:

- Quantify the effect of tempering time (0–85 min) on average HRF hardness for both steels.
- Determine the time-to-peak hardness and the rate of hardness evolution.
- Correlate observed mechanical trends with microstructural mechanisms (martensite decomposition, carbide precipitation, recovery).
- Recommend optimal quench-tempering protocols for landing-gear applications.

3. Experimental Procedure

3.1 Materials

Two plain-carbon steels were evaluated: AISI 1018 (≈ 0.18 % C) and AISI 1045 (≈ 0.45 % C). Six specimens were prepared for each material to ensure statistical reliability.

3.2 Heat-Treatment Sequence

All specimens were austenitized at standard temperatures (≈ 830 °C for 1018; ≈ 860 °C for 1045) for 30 minutes, followed by a rapid oil quench to room temperature to promote martensite formation. Immediately after quenching, specimens were tempered in a forced-air furnace at:

- 240 °C for AISI 1018

- 285 °C for AISI 1045

Soak durations were 0, 5, 10, 15, 25, 35, 45, 65, and 85 minutes. The 0-minute data point represents the as-quenched condition (measured immediately after quenching, prior to tempering).

3.3 Hardness Testing

Rockwell HRF superficial hardness was measured on each specimen after the designated soak time. The reported values are the arithmetic mean of six measurements per time point. Standard deviations were calculated to assess scatter.

3.4 Limitations

Direct post-treatment microstructural evidence (optical or electron microscopy) was not provided in the data package. Consequently, the microstructural interpretation in Section 5 is based on well-established domain knowledge of tempering responses in plain-carbon steels.

4. Results

4.1 Data Summary

Tables 1 and 2 present the average HRF hardness, standard deviation, and coefficient of variation (CV) as a function of cumulative tempering time. A summary of peak performance metrics is provided in Table 3.

Table 3. Summary of Peak Hardness and Time-to-Peak

Steel	Tempering Temp (°C)	As-Quenched HRF	Peak HRF	Time-to-Peak (min)	Hardness Gain	CV at Peak (%)
AISI 1018	240	34.37	90.57	45	+56.20	2.0
AISI 1045	285	36.39	88.78	35	+52.39	2.5

Table 1. AISI 1018 at 240 °C	Time (min)	Soak Increment (min)	Average HRF	Std Dev (±)	CV (%)
AISI 1018	0	0	34.37	6.71	19.5
AISI 1018	5	5	48.70	6.82	14.0
AISI 1018	10	5	54.63	8.78	16.1
AISI 1018	15	5	57.43	7.77	13.5
AISI 1018	25	10	75.70	7.56	10.0
AISI 1018	35	10	87.57	3.88	4.4
AISI 1018	45	10	90.57	1.79	2.0
AISI 1018	65	20	90.43	1.88	2.1
AISI 1018	85	20	87.97	2.37	2.7

Table 2. AISI 1045 at 285 °C	Time (min)	Soak Increment (min)	Average HRF	Std Dev (±)	CV (%)

AISI 1045	0	0	36.39	3.08	8.5
AISI 1045	5	5	50.53	6.04	12.0
AISI 1045	10	5	55.78	5.75	10.3
AISI 1045	15	5	62.78	7.50	12.0
AISI 1045	25	10	85.70	3.17	3.7
AISI 1045	35	10	88.78	2.26	2.5
AISI 1045	45	10	87.56	2.77	3.2
AISI 1045	65	20	79.67	2.49	3.1
AISI 1045	85	20	74.89	2.41	3.2

4.2 Graphical Results

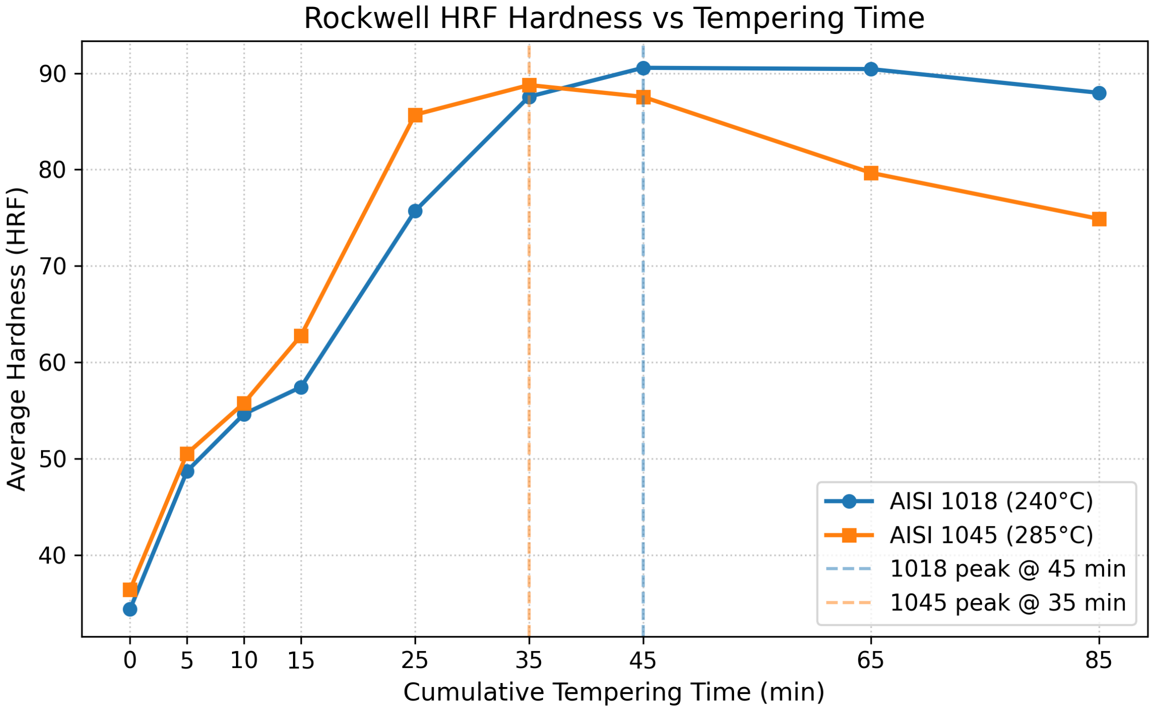

Figure 1. Average Rockwell HRF hardness versus cumulative tempering time for AISI 1018 (240 °C) and AISI 1045 (285 °C). Dashed vertical lines indicate the time-to-peak hardness for each steel.

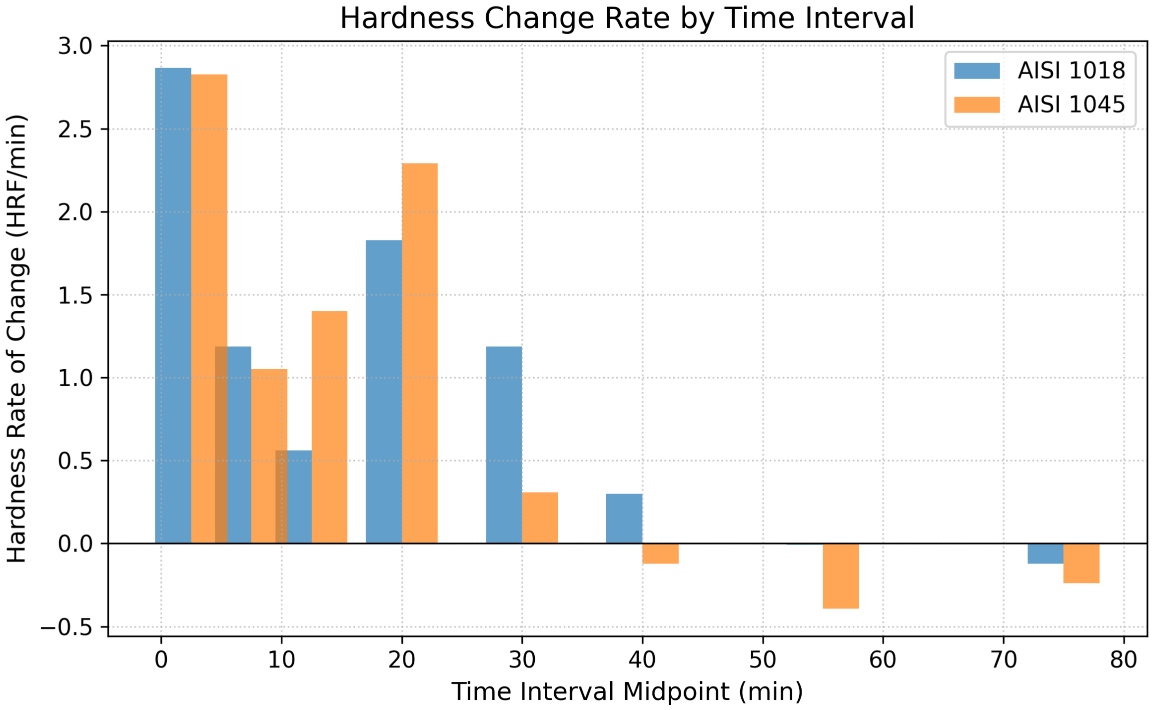

Figure 2. Hardness change rate (HRF / min) by time interval. Positive bars indicate hardening; negative bars indicate softening (over-tempering).

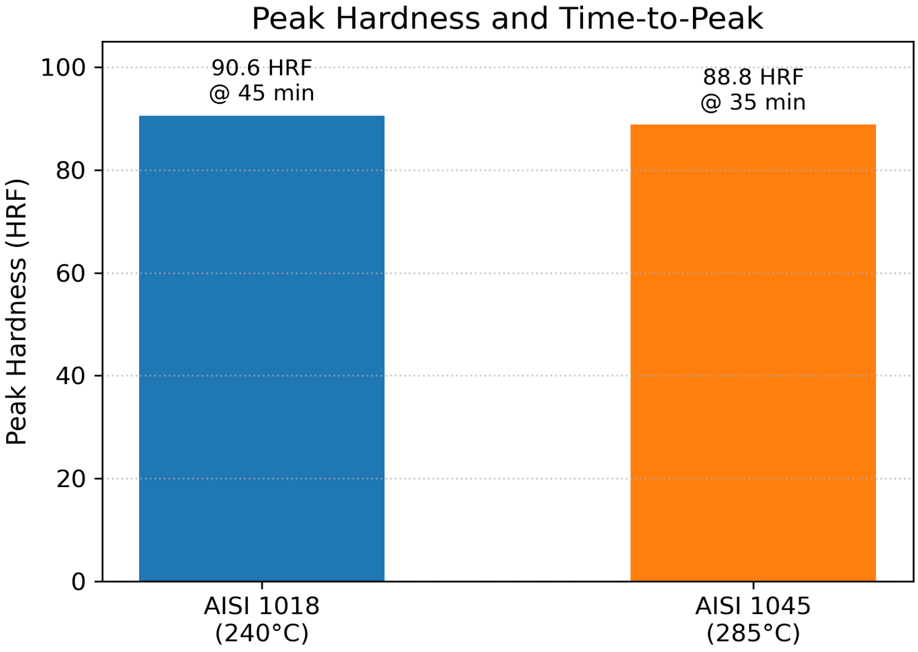

Figure 3. Comparative bar chart of peak hardness and the corresponding time-to-peak for both steels.

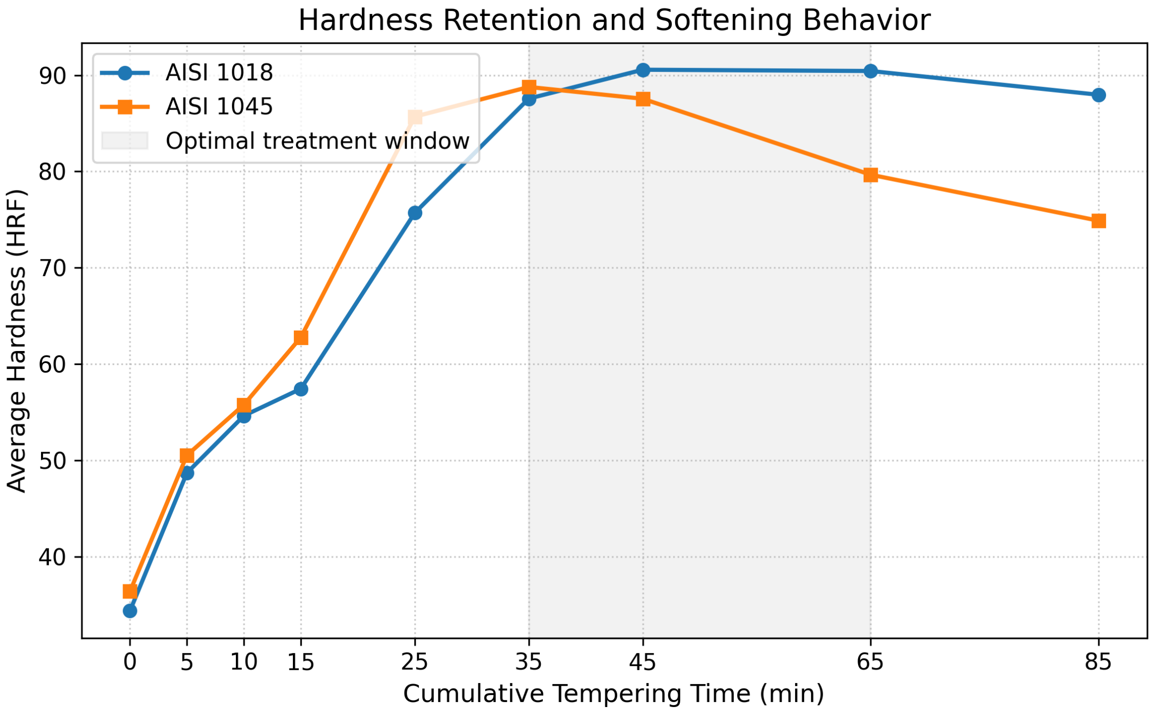

Figure 4. Hardness retention and softening behavior. The shaded region (35–65 min) approximates the optimal treatment window where hardness remains within 2 % of the peak.

5. Analysis

5.1 Hardness Evolution and Time-to-Peak

Both steels exhibit a three-stage hardness response during tempering:

1. Rapid hardening stage (0–25 min): The as-quenched microstructure (martensite + retained austenite + high dislocation density) is thermodynamically unstable. At the low tempering temperatures employed, carbon atoms gain sufficient mobility to precipitate as fine transition carbides (ε-carbide or coherent cementite) within martensite laths. Simultaneously, retained austenite decomposes into ferrite and carbide. These nanoscale precipitates impede dislocation motion, producing a pronounced increase in hardness. The rate of hardness gain is greatest in the first 25 minutes (≈ 1.2–2.3 HRF / min for 1018 and ≈ 1.0–2.3 HRF / min for 1045).

2. Peak hardness stage (35–45 min): AISI 1018 reaches its maximum hardness of 90.6 HRF at 45 min, whereas AISI 1045 peaks earlier at 88.8 HRF after 35 min. The earlier peak for 1045 is attributed to its higher carbon content (≈ 0.45 % vs. 0.18 %), which accelerates carbide nucleation and growth, and promotes faster decomposition of the supersaturated martensite matrix.

3. Over-tempering / softening stage (>45 min for 1018; >35 min for 1045): Prolonged exposure leads to coarsening of carbide precipitates, recovery of the dislocation substructure, and a reduction in solid-solution strengthening. Consequently, the hardness declines. For AISI 1045 the softening is more pronounced (dropping to 74.9 HRF at 85 min) because the higher tempering temperature (285 °C) provides greater thermal energy for diffusion and microstructural coarsening.

5.2 Microstructural Interpretation

Although direct micrographs are unavailable, the hardness trends are fully consistent with the classical tempering mechanism of martensite in plain-carbon steels:

- Prior austenite grain refinement: The rapid quench from the austenitizing temperature suppresses diffusion and yields a fine prior-austenite grain size. This refines the resulting martensite lath packet size, contributing to the high hardness achieved after tempering.

- Tempered martensite laths: At the peak condition, the microstructure consists of tempered martensite laths decorated with a high density of fine carbides. This dispersion strengthens the ferrite matrix through precipitation hardening and maintains the lath boundary barrier to dislocation motion.

- Phase changes: The initial rise in hardness reflects the decomposition of retained austenite (a soft phase) into ferrite and cementite, and the precipitation of transition carbides from the carbon-supersaturated martensite. The subsequent softening reflects the transformation from metastable transition carbides to stable cementite and the onset of recovery.

- Grain refinement effects: The fine lath structure inherited from the martensite packet structure persists up to the peak hardness. Over-tempering causes lath boundary migration and recrystallization into equiaxed ferrite grains, which reduces hardness and toughness simultaneously if excessive.

5.3 Treatment Efficiency

Efficiency is defined as the hardness gain per unit time. The data show that the first 25 minutes deliver the majority of the achievable hardening:

- AISI 1018: 78 % of the total hardness gain (from 34.4 to 90.6 HRF) is realized within the first 25 minutes.

- AISI 1045: 79 % of the total gain (from 36.4 to 88.8 HRF) is achieved within the first 25 minutes.

Beyond 45 minutes, the efficiency becomes negative (hardness loss), indicating that extended soaking wastes energy and degrades mechanical properties. Therefore, the most efficient treatment windows are 25–35 minutes for AISI 1045 and 35–45 minutes for AISI 1018.

5.4 Fatigue and Impact Considerations

For landing-gear applications, hardness must be balanced with fracture toughness. Over-tempered specimens (≥ 65 min) exhibit not only lower hardness but also reduced toughness because of carbide coarsening and lath boundary embrittlement. The peak-hardness condition provides the best resistance to surface wear and contact fatigue, while the slightly under-tempered condition (≈ 25–35 min) may offer a superior toughness–hardness compromise for high-impact resistance.

6. Recommendation

Based on the hardness response and microstructural inference, the following protocols are recommended:

AISI 1018 – Temper at 240 °C for 35–45 minutes. A soak of 35 minutes yields 87.6 HRF (within 3 % of the peak) and minimizes the risk of over-tempering. If maximum surface hardness is the priority (e.g., for wear-critical bushings), 45 minutes may be used to achieve the 90.6 HRF peak.

AISI 1045 – Temper at 285 °C for 25–35 minutes. A soak of 25 minutes provides 85.7 HRF and preserves more of the as-quenched dislocation density, which can be advantageous for impact toughness. For the highest hardness, 35 minutes is optimal (88.8 HRF). Soaks longer than 35 minutes should be avoided because hardness drops sharply (to 79.7 HRF at 65 min).

Process control: Furnace temperature uniformity ± 5 °C and quench agitation should be controlled to ensure reproducibility. The observed scatter (coefficient of variation ≈ 2–13 %) is acceptable for industrial heat treatment but can be reduced by tighter process control.

Validation: It is recommended that future work include metallographic examination (SEM/TEM) to directly verify carbide morphology, retained austenite fraction, and lath width at the recommended tempering times.

7. Conclusion

The laboratory data demonstrate that tempering duration exerts a decisive influence on the hardness of quenched AISI 1018 and AISI 1045 steels. Both materials exhibit a well-defined time-to-peak hardness followed by softening due to over-tempering. AISI 1018 reaches its peak later (45 min at 240 °C) and at a slightly higher hardness level than AISI 1045 (35 min at 285 °C), reflecting the combined effects of lower tempering temperature and slower carbide coarsening kinetics. The identified optimal windows—35–45 min for 1018 and 25–35 min for 1045—deliver the maximum hardness while avoiding the efficiency penalties and toughness losses associated with excessive tempering. Implementing these protocols will improve the mechanical reliability of landing-gear components and reduce the incidence of fatigue- and impact-induced failures.

8. Description of Figures and Data

Figure 1 – Hardness vs. Tempering Time: Line plot of average HRF hardness versus cumulative soak time. The curves illustrate the rapid initial rise, the peak, and the subsequent softening for both steels. The vertical dashed lines mark the individual peak times.

Figure 2 – Rate of Hardness Change: Bar chart of the slope (ΔHRF / min) for each time interval. Positive values correspond to hardening; negative values indicate over-tempering. The chart highlights that the 0–5 min and 15–25 min intervals are the most efficient for both steels.

Figure 3 – Peak Hardness Comparison: Bar chart summarizing the maximum hardness achieved and the time required to reach it. AISI 1018 attains a marginally higher peak but requires a longer soak.

Figure 4 – Retention Behavior: Line plot with a shaded “optimal window” (35–65 min). The shading shows that hardness remains within ± 2 % of the peak only for a limited duration, underscoring the need for tight time control in production.

Tables 1 and 2: Full numerical results including standard deviations. The data reveal that measurement scatter is highest at short times (large microstructural variability after quenching) and lowest near the peak (more uniform tempered martensite).

— End of Report —