Metallurgical Principles Associated with Size Changes in Carburized Steel

As steel is heated above 1350°F its microstructure becomes Austenite (Austenitic)

Hardness values noted below are for illustration only and are not accurate:

Microstructural Phase	Relative Size	Characteristic
A = Austenite	Smallest	Soft Ductile (think 20 HRC)
M_t = Tempered Martensite	Slightly smaller than M_u	Not Quite as hard as M_u but tougher (think 60 HRC)
M_u = Untempered Martensite	Largest	Hard Brittle (think 64 HRC)

For simplicity the following microstructural phases are not discussed:
Ferrite, Cementite, Bainite Carbide

Also not discussed are the coefficients of thermal expansion of the various microstructural phases.

For this document tempering is inferred to mean the reheating process after quench hardening.

There are two ways that Austenite can be transformed into Martensite

Quenching:
If Austenite is quenched fast enough to below the Martensite Start Temperature (about 400F) it transforms into the larger Untempered Martensite unless it is constrained from growth by strong enough Untempered Martensite or Tempered Martensite that does not provide enough room for the Austenite to become Untempered Martensite.

Mechanically:
Austenite can also be transformed into Untempered Martensite by mechanical deformation (working). Deformed Austenite becomes Untempered Martensite unless it is constrained from growth by strong enough Untempered Martensite or Tempered Martensite that does not provide enough room for the Austenite to become Untempered Martensite.

As the part cools further below the Martensite Start Temperature more of the smaller Austenite converts to the larger Martensite until the remaining Austenite (Retained Austenite) is constrained from transforming to Untempered Martensite. This is because the Untempered Martensite is strong enough to prevent the further transformation from Austenite to Untempered Martensite. Essentially there is no room for the Austenite to grow into Untempered Martensite.

If the part is Tempered the larger Untempered Martensite become the slightly smaller Tempered Martensite which allows some of the Retained Austenite to convert to Untempered Martensite.

Retained Austenite can also be converted to Untempered Martensite by three mechanisms:

Mechanically:
Additional (retained) Austenite can also be transformed into additional Untempered Martensite by mechanical deformation (working). Deformed Austenite becomes Untempered Martensite unless it is again constrained from growth by strong enough Untempered Martensite or Tempered Martensite that does not provide enough room for the Retained Austenite to become Untempered Martensite.

Tempering
Reheating (Tempering) the part will transform the larger stronger Untempered Martensite into slightly smaller softer tougher Tempered Martensite that again allows room for some of the Retained Austenite to convert to Untempered Martensite. Typical tempering temperatures for carburized steel are 325F +/-25F.

Long Times
Since Untempered Martensite is not an equilibrium microstructural phase given enough time (and/or probably enough mechanical action) it will continue to convert to Tempered Martensite allowing more room for Retained Austenite to transform to Untempered Martensite. Tempered Martensite is also not an equilibrium microstructural phase which given enough time will have properties associated with a slightly higher tempering temperature.

Tempering is a time and temperature dependent metallurgical mechanism. Therefore more tempering will occur for a given tempering time with a higher the tempering temperature or a longer the tempering time at a given tempering temperature.