WORTHINGTON INDUSTRIES

Technical Support White Paper

Date: May 1, 2020

Title: Residual Stress & Warpage

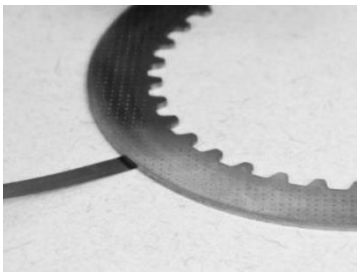
Products Affected: Flat parts produced from plain carbon cold rolled steel

Topic: Part Warpage During Service Conditions

Overview:

In today's world, there are increasing demands for enhanced flatness requirements as related to design performance. Specifically, the newest 8, 9 and 10 speed transmissions were developed by automotive and transmission OEMs to replace legacy 6 speed transmissions for fuel efficiency gains aimed at meeting fleet CAFÉ standards. New programs market wide were trialed, tested and validated for the launch of these transmission variants. These launches involved several automotive manufacturers starting in 2015. Cold rolled strip material was sourced from multiple steel suppliers for the manufacturing of the plates.

Summary of Issue:



An increasing issue that is being encountered by transmission component stampers is plate warpage at service conditions. Following the launch of initial 8, 9 and 10 speed transmissions, testing validation issues were encountered related to part warpage at service conditions temperatures. The warpage in turn resulted in localized hot spots in the transmission and premature test failures. These tendencies were noted in different transmissions and with steel from different cold rolled strip providers.

In most cases, the plates met print flatness spec off the stamper process, but then after exposure to heat that is representative of in-service conditions, the plates warped out-of- flat relative to specification requirements. It is believed that this warpage is the result of variable residual stresses present in the cold rolled steel strip from which the plates are stamped.

Recommendations:

Cold rolled strip materials produced by different suppliers to the same material specification exhibited different warpage response to service conditions, ranging from severe warpage to no meaningful warpage. Some suppliers added additional processing and costs to mitigate the effect of residual stresses and match the performance of other products in the market. The added risk of these counter measures is potential lead time extensions and less flexibility to react to customer demand changes.

Auto manufacturers initially sought a predictive test that would enable a product to be "certified" or "guaranteed" not to warp under service conditions. Extensive time was spent evaluating numerous research level techniques for quantifying residual stress in materials, but no techniques were identified suitable for production requirements.

Alternatively, an extensive experiment was conducted to study the impact of different processing conditions on the tendency for a cold rolled strip product to warp at elevated temperature. Efforts were made to isolate cold rolled strip processing variables and identify which were most influential in the creation of residual stresses as they might relate to plate warpage. Additionally, different geometries tested at service condition temperatures to evaluate impact to the propensity to warp. Test fixtures were developed to measure the flatness of these geometries before and after thermal treatments. Cold rolled strip samples were obtained before and after roller leveling to also review the impact of this operation on results.

Plan:

With the intent of evaluating a robust range of processing conditions that are used for plain carbon cold rolled strip production, all but three primary processing variables were controlled:

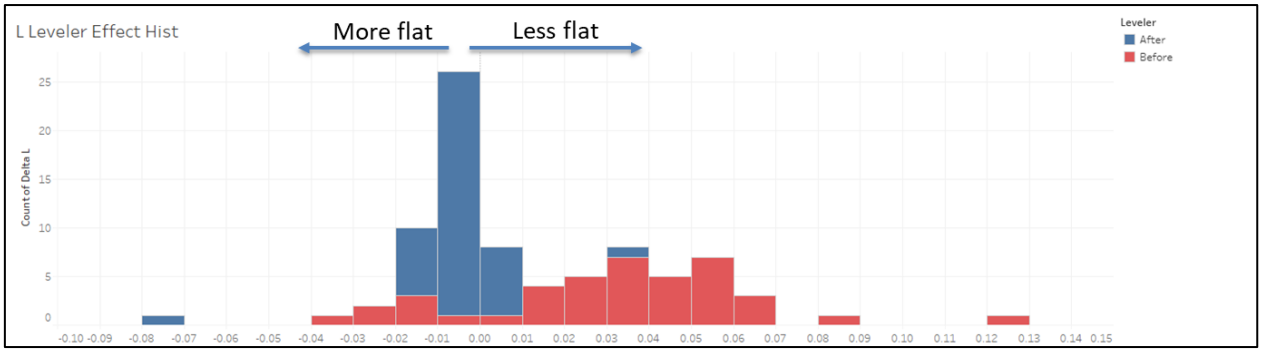
- Different cold rolling mills
- Varying cold reduction percentages
- With & without annealing steps

From these variables, 16 unique processing conditions were used to create test samples that represent the extremities of realistic processing limits to produce flatness critical cold rolled strip steel. A common plain carbon steel grade used for transmission components was selected for the study.

Processing Sequence	Worthington Plant	Final Thickness
A	A	A
A	A	B
A	B	A
A	B	B
B	A	A
B	A	B
B	B	A
B	B	B
C	A	A
C	A	B
C	B	A
C	B	B
D	A	A
D	A	B
D	B	A
D	B	B

Test samples were roller leveled to replicate pre-stamping press leveling. Different geometry specimens were created from the test samples by stamping and by waterjet cutting. All specimens were measured for flatness, subjected to service condition temperatures, and then re-measured for flatness.

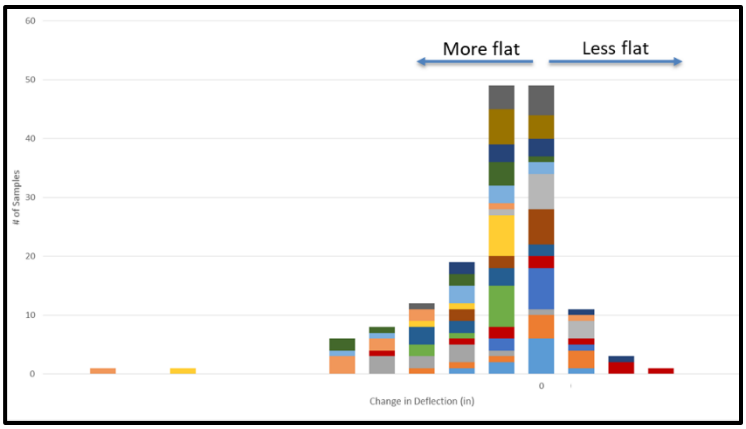
Impact of Press Leveling on Part Warpage at Service Temperature



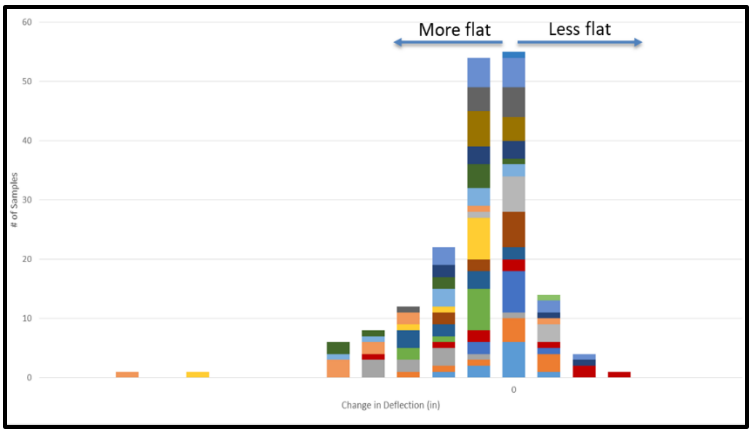
Outcome:

Cold rolled strip products were produced using a wide variety of processing parameters and subsequently tested for tendency to warp. All products exhibited minimal warpage at service conditions.

Warpage – Geometry A



Warpage – Geometry B



This provides a high level of confidence in the stability of Worthington's cold rolled strip steel products for the full range of ordered material specifications in the prevention of part warpage in service. As a result, key findings relevant to Worthington cold roll strip products were identified:

- Engineered cold rolled strip can be supplied to provide part stability in service conditions, independent of grade and material thickness
- Part stability can be achieved independent of processing locations and type of cold rolling equipment
- Part stability can be achieved without adding annealing steps into the cold roll strip process

Based on these findings the manufacturer is not limited in their grade and/or material specification selection, their supply chain is not limited and faster reaction to demand changes is enabled with opportunities to reduce cost.