Residual Stress Measurements of Cast Aluminum Engine Blocks Using X-Ray Diffraction

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Abstract

Residual stresses in cast aluminum engine blocks were mapped using x-ray diffraction. Data collection on as-cast and annealed engine blocks was completed using a large sample stress analyzer with chrome radiation. Automated coordinate-mapping of the radial and hoop stresses was performed. Data analysis was performed on the aluminum (311) reflection using new LabVIEW software, developed for improved efficiency and quality of data analysis. Analysis of the hoop stress results showed an overall reduction in compressive stresses and increased uniformity in the stress levels over the mapped surface with increasing heat-treatment. The radial stress results, however, shifted from compressive to tensile with no change in uniformity with increasing heat treatment. This shift may be attributed to the complex geometry of the engine block resulting in the radial direction being constrained.

Background

- Residual stresses identified in cast aluminum engine blocks:
  - Result from differential cooling during processing
  - Distort critical features during machining
  - Difficult to maintaining dimensional tolerances (i.e. bearing journals)
- The engine blocks are subjected to a T5 stress relief treatment prior to machining:
  - Provides residual stress reduction
  - Adds complexity to the process (major production volume limiting step)
  - Alternate stress relief cycles (w /greater throughput) would be beneficial.
- To provide understanding, the residual stresses in the engine block were mapped using x-ray diffraction with a large specimen stress analyzer – gantry system at the Residual Stress User Center (RSUC) at ORNL.

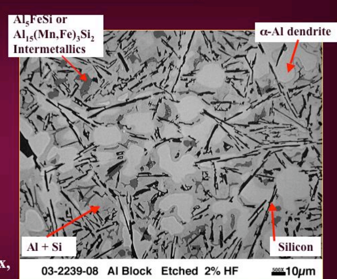
Five Engine Blocks Were Examined

Samples

- Two engine blocks: as-cast condition
- Three blocks were heat treated: 230, 248 and 270°C for 4 hours

Material Properties [1]

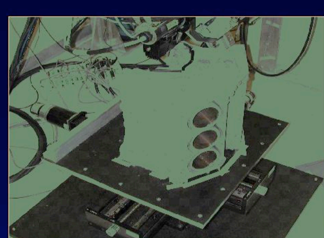
- Die cast SAE 383.0 (UNS A03830) alloy aluminum
- Young's Modulus = 70 GPa
- Poisson's Ratio = 0.33
- Nominal composition (wt %): 2.0 to 3.0 Cu, 0.1 Mg max, 0.50 Mn max, 9.5 to 11.5 Si, 1.3 Fe max, 0.30 Ni max, 3.0 Zn max, 0.15 Sn max, 0.50 others (total) max, bal Al.



Metallographic analysis revealed the expected microstructure with no apparent change along the cross-section normal to the diffracting surface.

Experimental

- Shielded enclosure: 15 x 8.2 x 9.2ft (L x W x H)
- X-ray stress analyzer mounted to overhead gantry-system: XYZ motion
- Remote sample positioning and data collection via LabVIEW software
- Accommodating a variety of samples:
  - 100 lb. - table-top XYϕ stages
  - 250 lb. - floor-mounted XYϕ stages
  - 250 lb. - floor



Samples stage modified for large engine blocks

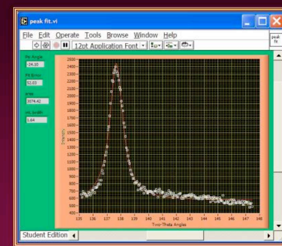
X-Ray Measurement Conditions

Parameter	Condition
Equipment:	TEC Model 1600 x-ray stress analyzer Position sensitive detector (PSD), 14°2Θ range
Power:	52.5 W; 35 kV, 1.5 mA
Radiation:	Cr $K\alpha_1$, $\lambda = 2.28970$ Å
Source to specimen distance:	220 mm
Specimen to detector distance:	220 mm
Tilt axis and angles*:	Ω [3A], Ψ = 0, ±9.6, ±13.6, ±16.8, ±19.5, ±21.9, ±24.1, ±26, ±28.1, ±30° (equal steps of $\sin^2\psi$)
Scans:	0.06 °2Θ/step; 60 sec/scan; 135-149°2Θ
Mapping:	33 points; radial distribution
Stress Measurement:	hoop and radial stresses

*For the radial stress, Ψ values of +16.8 through +30° could not be used due to clearance issues.

New analysis software uses "$\sin^2\psi$" technique [3(B)]

- LabVIEW software developed to overcome short-comings [5] of old analysis software [2,4]
  - Assumes a biaxial stress state
  - Improved accuracy as entire peak profile is fit
  - Automated or manual mode analysis can be performed

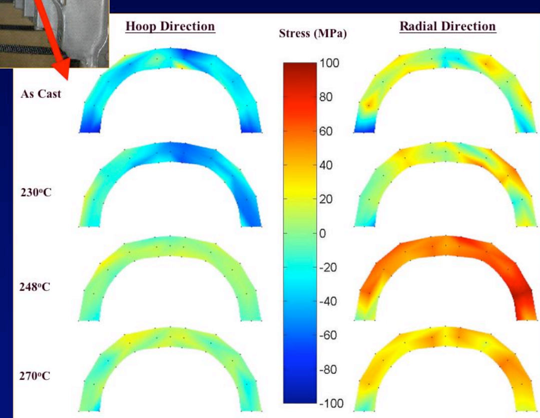


Displays allow the user to evaluate the quality of the analysis and improve the accuracy of the stress calculation.

Results

The main bearing saddle area was the area of interest for stress mapping.

Plots of surface stresses for the as-cast and heat treated engine block were generated with the use of Microsoft Excel and Matlab. The applied color scheme was equally scaled for visual comparison of the different heat treatments.



Discussion

The 248°C profile does not appear to follow the trend in the data, hardness measurements were taken to verify that the engine blocks were not mislabeled. Results of the hardness testing showed decreasing hardness with increasing heat treatment.

Evaluation of the hoop stress results shows a trend in the compressive residual stresses towards zero stress and a more uniform profile with increasing heat treatment. This trend make sense based on the four considerations for stress relief heat treatment (heating temperature & time, stress magnitude, and desired use of the component).

Evaluation of the radial stress results shows a trend of increasing then decreasing stress in the tensile region with no improvement in stress distribution with increasing heat treatment. Given the complex geometry of the engine block, complete stress relief in the radial direction may be constrained.

References

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[5] T.M. Ely, "Investigation of the Repeatability of Stress Values Reported by TEC Software." [Unpublished work], 2001.

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