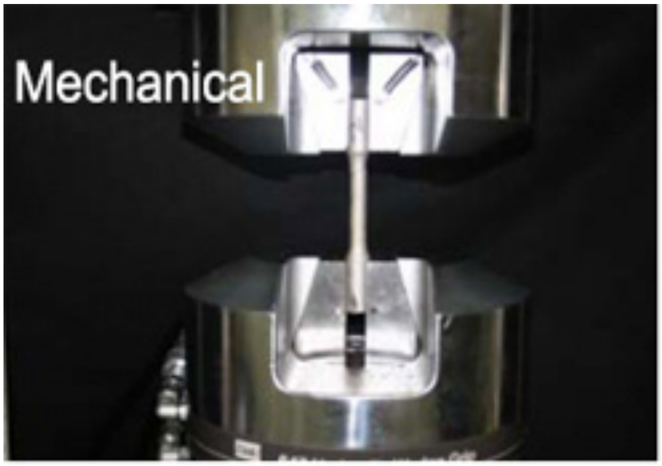
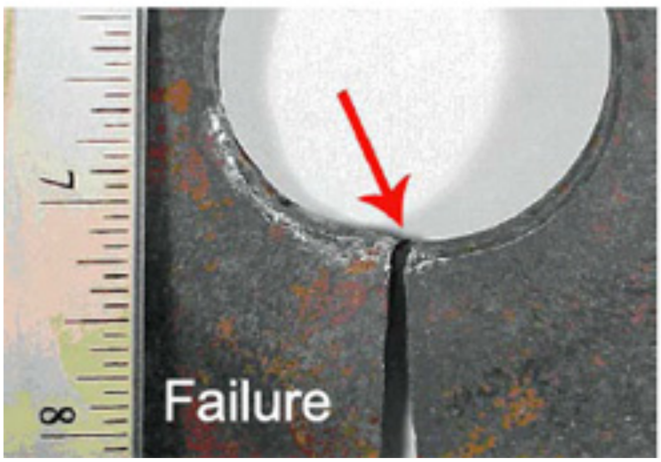
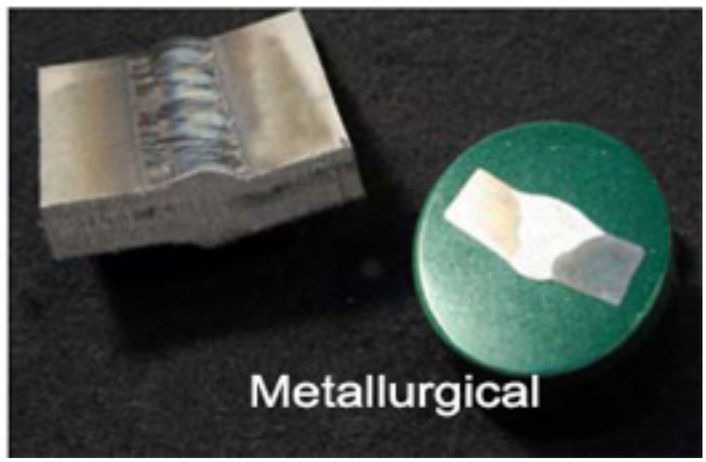
MSi Investigative Summary

Metallurgical Testing Laboratory

MSi provides the following Metallurgical Testing and Failure Analysis Services:





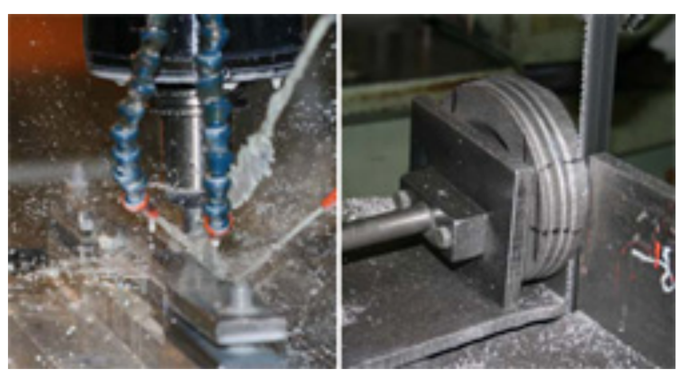


- Metallurgical Lab Services
- Mechanical Test Lab Services
- Metal Chemical Testing Lab Services
- Hardness Testing Services
- Failure Analysis Laboratory Services

Visit our **Metal Analysis** page for complete descriptions of each labs capability.

Our laboratory specializes in FAST turn-around of all testing and consulting services.

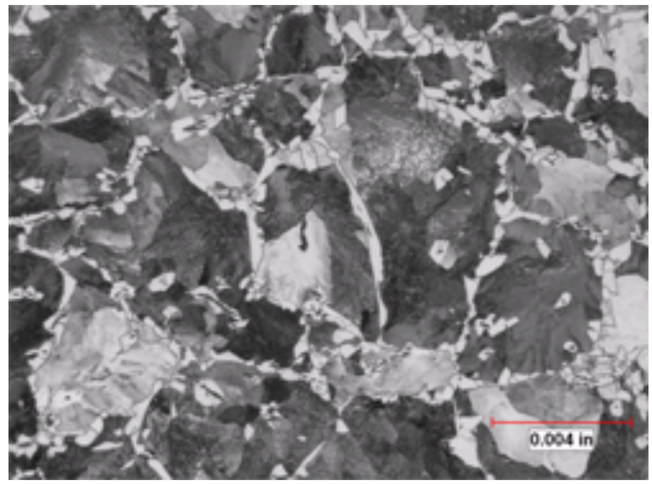
Our 10,000 sq. ft machine shop supports extensive machining capabilities toprocess large samples for fast delivery of test results:



- Eleven Band Saws
- Five abrasive cut-off saws
- Three CNC Tuning Centers
- Three CNC Milling Centers
- Two CNC Grinders

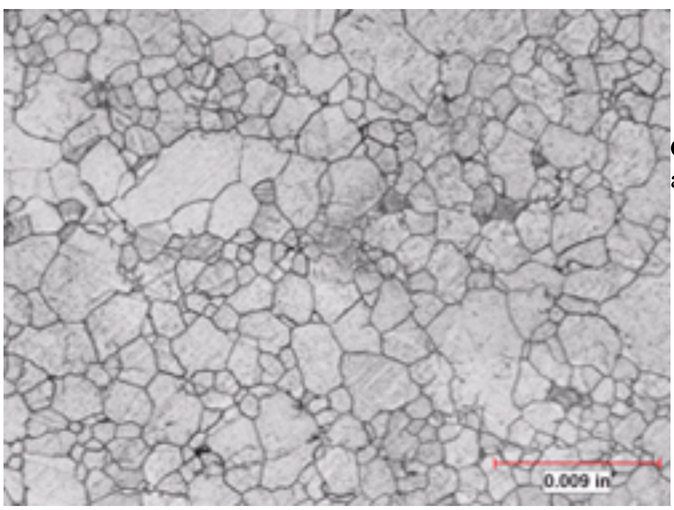
Call today to speak with one of our sales associates about how we can help you with your metallurgical testing requirements.

MSi's team of experienced engineers and technicians provide MetallurgicalAnalysis on the following materials;



Grain Size Examinations for:

- Plan Carbon / Alloy Steel
  - a) Hot Rolled
  - b) Martensitic
  - c) Oxidation Method (ASTM E112)
  - d) McQuaid-Ehn Method (ASTM E112)
- Stainless Steel
- Titanium Alloys
- Cast & Ductile Iron



Grain Size Exams using Clemex Image Analysis, performed in accordance with ASTM E1382

Heat Treatment - Daily Production Examinations and Problem Solving

Heat Treatment Microstructure Evaluations

1) Total Case Depth
2) Retained Austenite Depth
3) Surface Hardening
4) Partial and Total Surface Decarburization
5) Free Ferrite Percentage
6) Graphite Flake, Type & Size exams

7) Titanium Alpha Case and Beta Phase Determinations

The metallurgical testing laboratory at MSi is one of seven testing departments that provide daily metallurgical analysis to over thirty manufacturing industries every day. Metallurgical test reports are used identify any detrimental or rejectable conditions that require identification or explanation for the reading audience. In addition we provide photographic documentation with specific captions that give a photo story to the metallurgical report. Very often our clients are not technical and the pictures are critical to their understanding of our steel analysis report findings. (See example below).

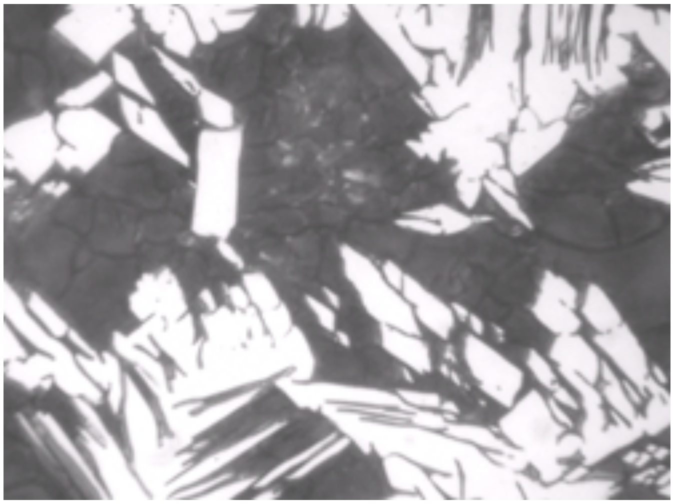


Photo 2 - Magnification: 1000X Location: HAZ (2205) at Mid-Thick. Etchant: Beraha's

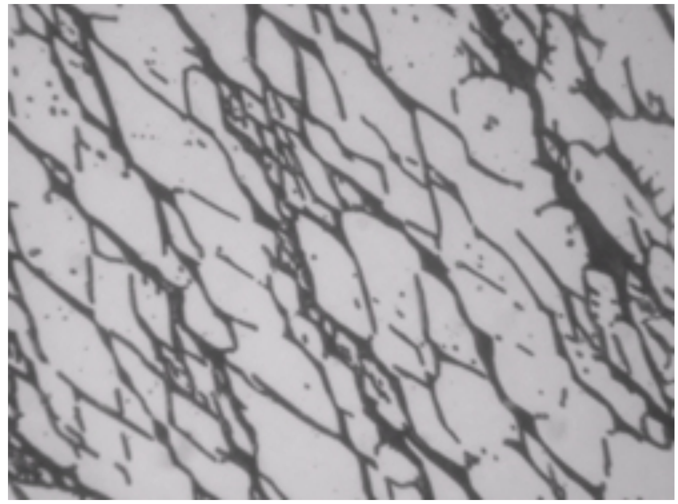


Photo 3 - Magnification: 1000X Location: Weld at Mid-Thickness Etchant: Beraha's

The Clemex Image Analysis System permits exceptional digital photography with the ability to perform automated microcleanliness (ASTM E45) and grain size (ASTM E1382) examinations. The motorized stage of our two Clemex systems also permits mosaic photomicrographs. These allow high resolution lower magnification photographs in a predetermined "grid" where the stage moves, snaps a shot, and then stitches the individual photographs back together into one seamless picture.

Call a member of our sales staff or ask to speak to an engineer to learn more about the metallurgical analysis capabilities of our laboratory.

BACKGROUND

One (1) failed steel bracket assembly for a Hummer vehicle was submitted to our metallurgical testing laboratory for a metal failure analysis investigation. The part reportedly failed at one of the two 90° bends during a fatigue test. It was also reported that an aluminum part to which the bracket had been attached for the duration of the test fractured at the anchoring point. The bracket material processing included hot rolling, pickling and oiling. No further background information was available. We were requested to determine the cause of the bracket assembly failure.

SAMPLE IDENTIFICATION

Part Description	Size	Material	Specification	No. of Samples
Hummer steel bracketF	11-gauge strip, 12"-long x 1"-wide	Carbon steel	ASTM A 569 replaced by ASTM A 1011 in 2000)	1

PERFORMED TESTING

Visual and Stereoscopic Examination
Scanning Electron Microscopy (SEM) Examination
Metallographic (Microstructural) Examination
Chemical Analysis
Hardness Testing

CONCLUSIONS

1. Based upon the performed the tests and examinations performed by our metallurgical testing laboratory, it is our opinion that the failure of the submitted steel bracket occurred by reverse bending fatigue failure mechanism followed by a rapid ductile overload fracture. Fatigue cracking initiated inside a 90° bend, where stresses are inherently high.

2. The fatigue cracks propagated under the cyclic test loads through ~90% of the load-bearing cross-section. The final rapid overload fracture occurred through the remaining narrow metal ligament adjacent to the apex of the bend.

3. Fatigue is a progressive (time-dependent) failure mechanism that leads to initiation of small cracks when a part is subjected to repeated or fluctuating stresses, which exceed the fatigue strength of the material. The maximum applied stresses are below the tensile strength of the material and, therefore, the failures occur gradually, over an extended period of time.

4. An appreciable area on the fracture surface was subjected to extensive post-failure wear damage; however, some better-preserved areas on the fracture were suitable for SEM examination. The examination revealed coarse, evenly-spaced crack progression marks, known as fatigue striations. Such features positively identified the failure mechanism as reverse bending fatigue. The coarse striation appearance implied a low-cycle, high-stress fatigue mechanism, with the loading stresses extending into the plastic zone of the stress-strain curve. Such striation appearance are indicative of excessive test loading conditions that required a metal failure analysis investigation to identify the root cause.

5. Metallographic examination of the bracket material revealed a uniform microstructure consisting of ferrite and pearlite, typical of a hot-rolled ASTM A 1011 carbon steel. No evidence was observed of pre-existing steel defects, excessive nonmetallic inclusions, or any other detrimental material conditions that could have contributed to the failure.

6. Hardness testing results met the requirements of ASTM A1011, Sheet and Strip Designations CS Types A and B. Chemical testing confirmed the bracket material as ASTM A 1011 carbon steel.

7. We respectfully recommend reviewing the fatigue test conditions, to identify the likely source of the excessive cyclic loading applied to the submitted bracket.

SUMMARY of TEST RESULTS

Visual and Stereoscopic Examination

1. Visual and stereoscopic examination of the bracket revealed that the failure occurred at one of the two 90° bends (see Photo 1, arrow).

2. The fracture surface showed two distinct regions. The first region occupied ~90% of the total fracture. It had a thumbnail-like shape, exhibited a relatively flat appearance with evidence of wear damage, and contained semi-circular crack progression lines (beach marks) emerging from a site on the inner surface of the bend. Beach marks are associated with propagation of fatigue cracks under cyclic bending and/or tensile loading The site of the beach marks emergence was identified as the crack origin. The second region was dark-colored and fibrous, and occupied the remaining ~10% of the surface. Fibrous appearance is commonly associated with ductile overload failures (see Photo 2, arrows).

3. The observed surface features are commonly associated with propagation of fatigue cracks under cyclic bending loading, followed by a rapid ductile overload fracture, when the reduced load-bearing cross-section could not carry the applied stresses.

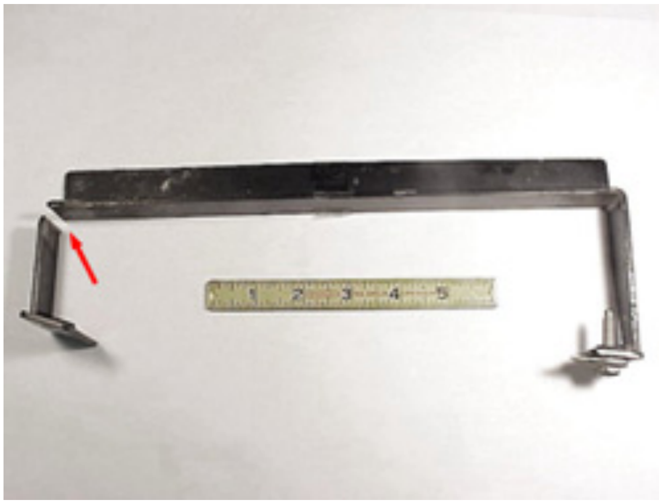


Photo 1: Failed bracket, as received

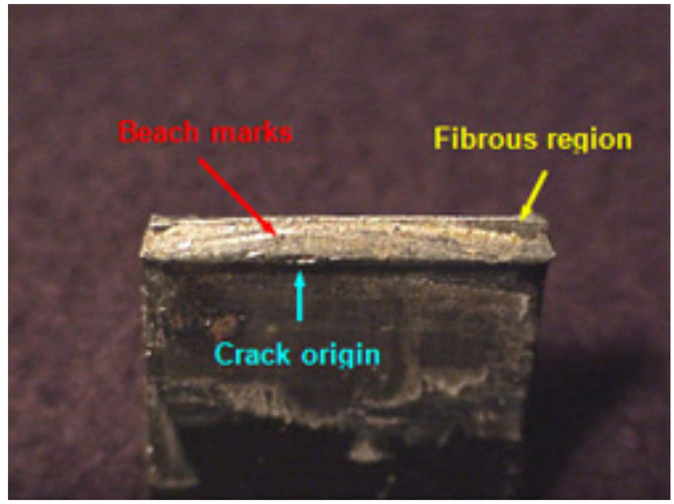


Photo 2: A close-up view of the fracture surface

Scanning Electron Microscopy (SEM)

1. An appreciable area on the fracture surface was subjected to extensive post-failure wear damage; however, some better-preserved areas on the fracture were suitable for SEM examination. The examination revealed coarse, evenly-spaced crack progression marks, known as fatigue striations (see Photo 3 on the following page). Such features positively identified the failure mechanism as reversed-bending fatigue.

2. The coarse striation appearance implied a low-cycle, high-stress fatigue mechanism, with the loading stresses extending into the plastic zone of the stress-strain curve. Such striation appearance may be indicative of excessive test loading condition.

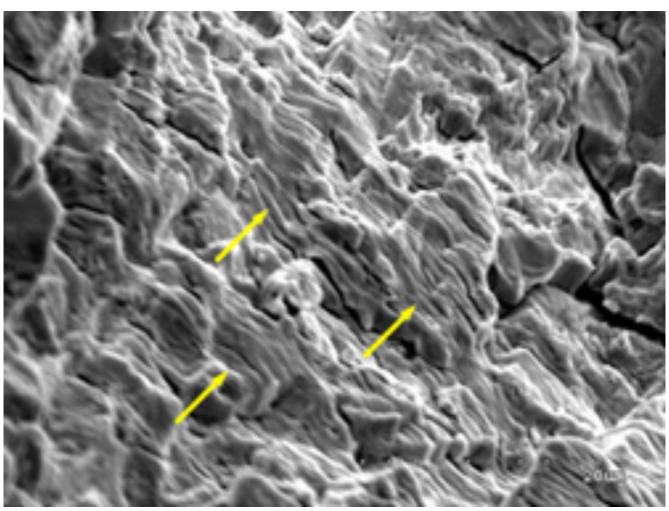


Photo 3: Magnification: 1,700X SEM view of fatigue striations (arrows) from reverse bending fracture

mechanism.

Metallographic Examination

1. Transverse and longitudinal sections removed from the submitted bracket revealed a uniform microstructure consisting of ferrite and pearlite, typical of a hot-rolled ASTM A 1011 carbon steel (see Photos 4 – 5).

2. No evidence was observed of pre-existing steel defects, excessive nonmetallic inclusions, or any other detrimental material conditions that could have contributed to the failure.

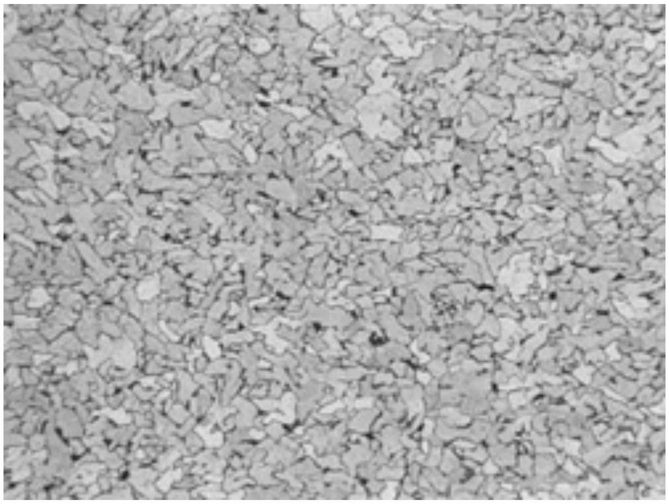


Photo 4: Mag: 200X: Etchant: 3% Nital Longitudinal cross-section

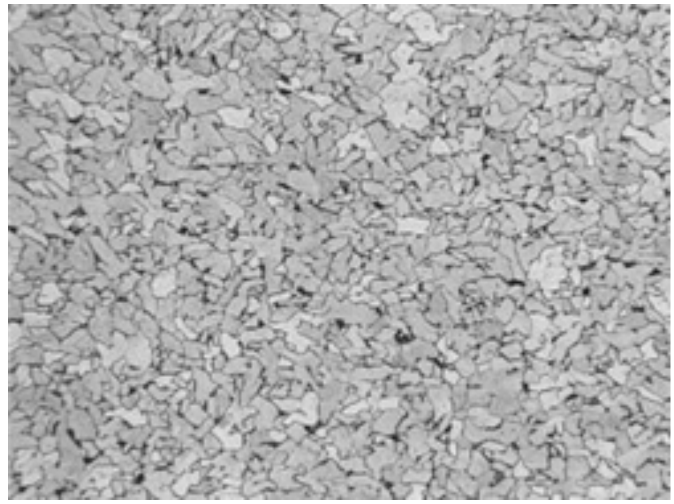


Photo 5: Mag: 200X Etchant: 3% Nital Transverse cross-section

Hardness Testing

1. Hardness testing results met the requirements of ASTM A1011, Sheet and Strip Designations CS Types A and B (75 HRB or less).

2. The results are shown in Table 1 attached.

Chemical Testing

1. Chemical testing confirmed the bracket material as ASTM A 1011 carbon steel.

2. The results are shown in Table 2 attached.

Table 1 – Hardness Testing*

Hardness, HRB		
71	71	71

* Testing performed in accordance with ASTM E18.

Table 2 – Chemical Testing*

Element	Bracket Material
Carbon	.10%

Manganese	.50
Phosphorus	.015
Sulfur	.013
Silicon	.01
Nickel	.02
Chromium	.01
Molybdenum	<.01
Copper	.03
Aluminum	.03

* Testing performed in accordance with ASTM E415.