MSi Testing & Engineering, Inc.
Your Source for Metallurgical Testing and Failure Analysis
1390 N. 25th Avenue
Melrose Park, IL 60160
708·343·3444
F A X·3033

ACCREDITED
CERT #0510-01

# *MSi Investigative Summary*

## BACKGROUND

Two (2) forged drag chains identified as MCV and 4B were submitted to our laboratory for a metallurgical investigation. Sample MCV exhibited a complete fracture through the single hole end with significant surface wear along the side of the chain. Sample 4B exhibited no evidence of cracking or surface wear. Drag chains are part of a drag assembly used to convey limestone and bentonite clay from rail hoppers to a bucket conveyor.

Reportedly, the two samples were drop forged hot from Cr-Mn alloy steel of low carbon content. A one-inch diameter pin hole of the fractured end and identical holes at the two-ear opposite end of the chains were machined to size. Heat treatment of the ID of the pin holes and all exposed chain surfaces consisted of carburizing to an effective case depth of .030 - .040” followed by tempering the core to 300 – 400 Brinell. Numerous failures of the single-hole end of the chains have reportedly occurred during service. No additional background information was available.

We were requested to determine the failure mechanism and origin of failure for chain sample MCV. Additionally, we were requested to compare the effective case depth and hardness, core hardness, chemical composition, and tensile strength properties of the two samples.

## SAMPLE IDENTIFICATION

| Description | Material | Heat Treatment | Condition |
|---|---|---|---|
| Drag Chain MCV | Cr-Mn Steel | Carburized, Hardened & Tempered | Fractured |
| Drag Chain 4B | Cr-Mn Steel | Carburized, Hardened & Tempered | No Damage |

## PERFORMED TESTING

Visual and Stereoscopic Examination
Scanning Electron Microscope (SEM) Examination
Metallographic (Microstructure) Examination
Hardness Testing
Chemical Testing
Tensile Testing

## CONCLUSIONS

1. Based upon the performed tests and examinations, it is our opinion that the failure mechanism of the submitted chain MCV was fatigue, which is a progressive failure mode occurring over time. The fatigue crack initiated at multiple sites associated with the side of the chain in contact with the drag conveyor. The failure of chain MCV was related to excessive abrasive service loading conditions of the side of the chain and not the quality of the forging or heat treatment. No evidence was observed of any pre-existing forging defects, quench cracks, or any material defect conditions at the fracture origin that could have contributed to the failure.

2. Applied in-service loading of the 5/32” wide trim-line of the chain (forging) abrasively removed the entire effective case of .030”. Removal of the hardened carburized case resulted in the initiation of fatigue cracks in the lower subsurface hardness of core material. Continued in-service loading stresses after abrasive removal of the effective case caused the fatigue crack to propagate to an approximate depth of 5/8”. Final ductile overload failure occurred when the remaining cross section adjacent to the pinhole could no longer support the applied load.

3. Scanning electron microscope (SEM) examination of the fracture features of chain MCV revealed striations (microscopic crack progression marks) associated with the origin of the failure and into the core, which verified that failure was the result of fatigue. Fatigue cracking propagated in a perpendicular direction over time from the worn side of the chain approximately 3/4” from hole center a distance of 5/8”. The fatigue zone was essentially 40% of the total fracture surface. The balance of the fracture was dimpled, which was characteristic of a ductile overload failure mechanism. Final overload failure occurred towards the 1” hole and through the wall thickness of the chain opposite the origin side towards the MCV logo surface of the chain.

4. Metallographic examination of the side of the chain that served as the origin revealed evidence of directionally cold worked grains and no evidence of a carburized case. The case was worn away during in-service conditions. The fracture path associated with the fatigue zone was transgranular, typical of a fatigue failure. No evidence was observed of quench cracking or pre-existing material defect conditions.

5. The effective case depth to 50 HRC minimum of the opposite side (trim-line) of the chain near the 1” hole was measured at .030”. The microstructure of the case consisted of small amounts of retained austenite in a matrix of tempered martensite, typical of a carburization heat treatment. The case hardness to a depth of .010” below the surface measured 60 HRC. The core microstructure consisted of tempered martensite with a core hardness of 37 HRC (363 HBW). The effective case depth and core hardness conform to the specified requirements.

## CONCLUSIONS (cont.)

6. The effective case depth to 50 HRC minimum of Chain 4B at the same location as the fracture origin of Chain MCV was measured at .045", which slightly exceeded the specified requirement of .030 – 040". The thicker case depth of the side suggests Chain 4B was not in service or subjected to different surface loading conditions. The microstructure of the case consisted of small amounts of retained austenite in a matrix of tempered martensite, also typical of a carburization heat treatment. The case hardness to a depth of .010" below the surface also measured 60 HRC. The core microstructure consisted of tempered martensite with a core hardness of 35 HRC (327 HBW), which was indicative of quench hardening and tempering after carburizing.
7. Chemical test results indicate that both chains were manufactured from Cr-Mn alloy steel. However, the material did not classify as any standard domestic steel grade, and most likely was from a foreign steel supplier. Chain MCV was most similar to AISI 51B20 boron treated steel as compared to Chain 4B, which was most similar to AISI 5120 steel without boron. The addition of boron during steel manufacturing of similar grades would provide for increased hardenability during heat treatment of similar section sizes and the same heat treatment cycles. The supplied steel grade was not a factor in the failure.
8. Tensile test results of core material between the pinholes of the individual chains indicate Chain MCV exhibited increased tensile and yield strength as compared to Chain 4B. The endurance limit (fatigue strength) of Chain MCV is greater than Chain 4B based upon the tensile test results.

## SUMMARY of TEST RESULTS

### Visual & Stereoscopic Examination

1. Sample MCV exhibited a complete fracture through the single 1" hole end and significant surface wear along the side of the chain. The sides of the chain correlate to the "flash" line formed during the hot forge and trimming operation. The "flash" line surface was also carburized during heat treatment and became severely worn during in-service conditions. (See Photos 1 – 4 on the following page)
2. The fracture surface of MCV was ultrasonically cleaned to remove any loose debris and to reveal any distinguishing characteristics. Cleaning revealed a "thumbnail" pattern from the side of the chain that extended into the core, which was typical of a fatigue failure. (See Photo 3 on the following page)
3. The balance of the fracture was classified as the final fracture zone as shown in Photo 3.
4. A close up view of the fracture origin associated with the worn surface of the chain is shown in Photo 4.

## Visual & Stereoscopic Examination (cont.)

**Photo 1**: View of the submitted Chain samples showing fractured MCV at the bottom and 4B at top.

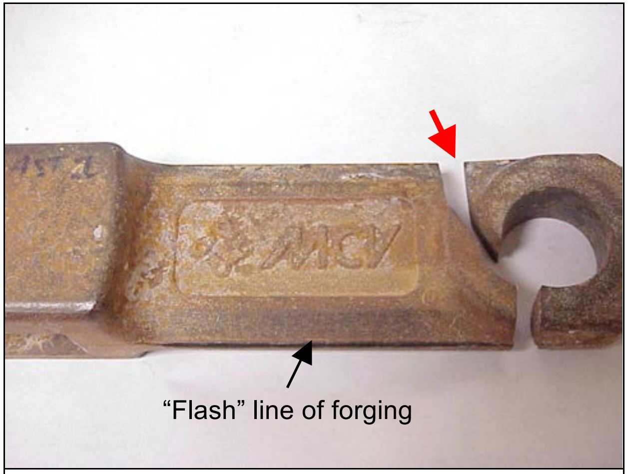

**Photo 2**: Close-up view of MCV and the location of the fracture at red arrow. Photo 3 shows cleaned fracture.

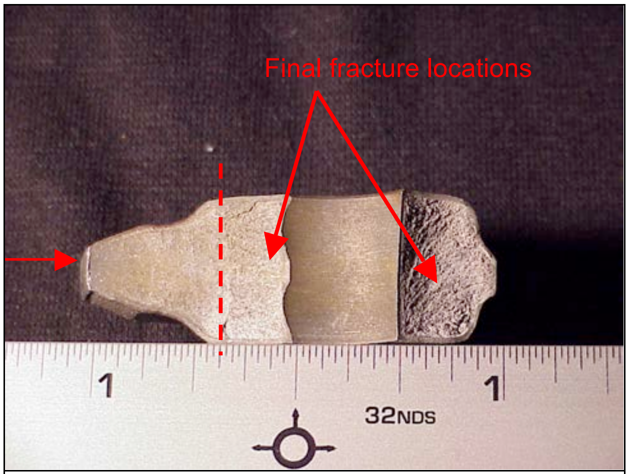

**Photo 3**: View of "thumbnail" pattern from red arrow to dashed red line, which was typical of fatigue failure. The red arrow also indicates the origin of failure, which was severely worn from in-service loading conditions.

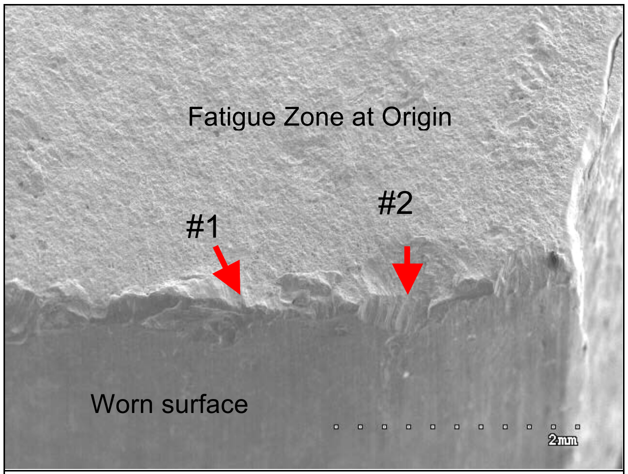

**Photo 4**: Close-up view of the severely worn surface that served as the origin of fatigue cracking. Two indents at red arrows served as stress concentrators. Mag: 15X

## Scanning Electron Microscope Examination

1. Scanning electron microscope (SEM) examination of the fracture features of chain MCV revealed striations (microscopic crack progression marks) associated with the origins at the worn surface, which verified failure of the chain was the result of fatigue. The striations were mildly oxidized, which altered their appearance and indicated fatigue cracking occurred over a period of time. Fine imperfections on the worn surface served as stress concentrators and sites of initial fatigue cracking. (See Photos 4 – 6)

2. Scanning electron microscope examination of the fracture features associated with the zones of final fracture revealed a dimpled surface, which was characteristic of ductile overload. (See Photos 7 and 8)

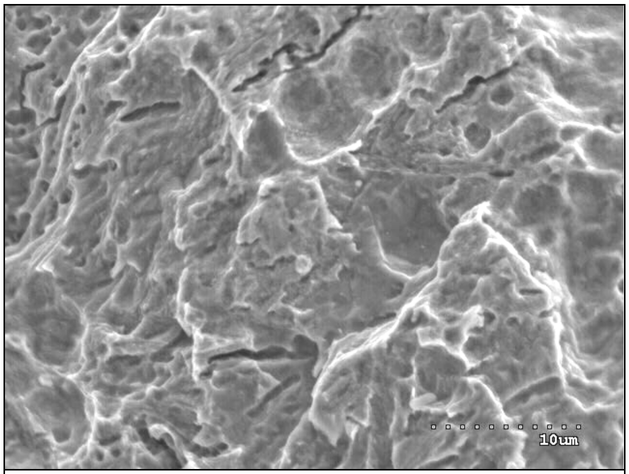

**Photo 5 –** Fracture features of origin #1 Mag: 1900X
SEM view of striations at origin associated worn side.

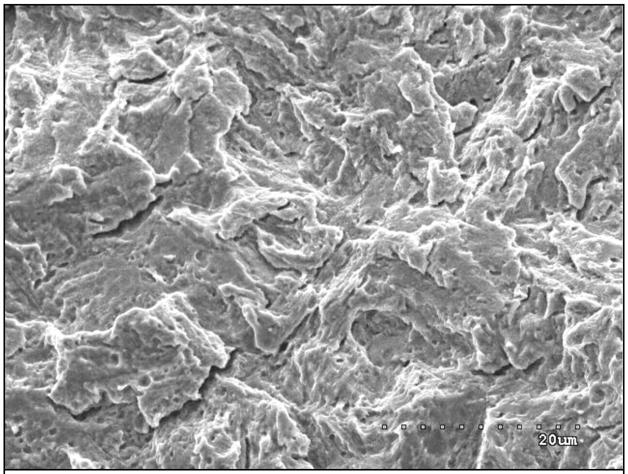

**Photo 6 –** Fracture features of origin #2. Mag: 1300X
SEM view of striations at origin associated with worn side

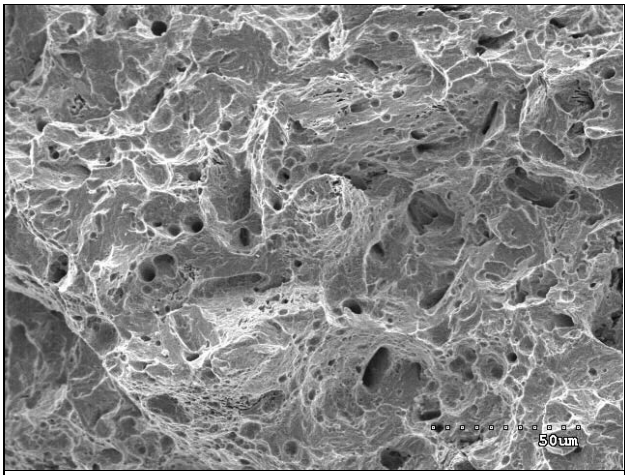

**Photo 7 –** Features of final fracture Mag: 400X
SEM view of a dimpled fracture, typical of a ductile overload final fracture.

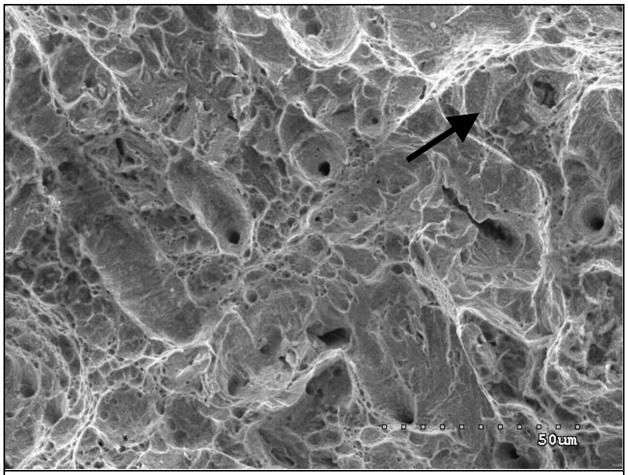

**Photo 8 –** Features of final fracture Mag: 500X
SEM view of a dimpled fracture, typical of a ductile overload final fracture.

## Metallographic Examination

1. Examination of the fracture profile at the origin of failure of Chain MCV revealed the carburized case was removed from the side of the chain during in-service loading conditions. The same location of Chain 4B revealed a carburized case to a depth of .038”. (See Photos 9 & 10)
2. Examination of the surface microstructure of Chain MCV away from the fracture origin revealed a total carburized case to a depth of .035”. The microstructure of the case consisted of small amounts of retained austenite in a matrix of tempered martensite. The same location of Chain 4B revealed a similar case microstructure. (See Photos 11 & 12)

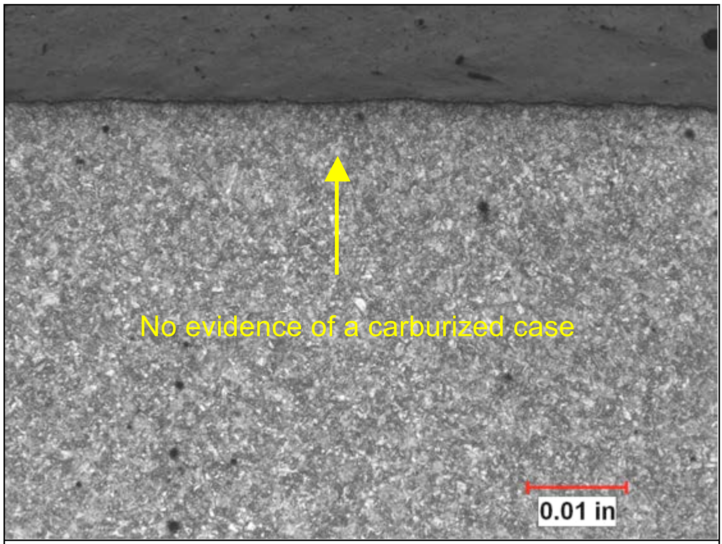

**Photo 9:** Mag: 50X; Etchant: 3% Nital
Chain MCV: No evidence of any carburized case at fracture origin.

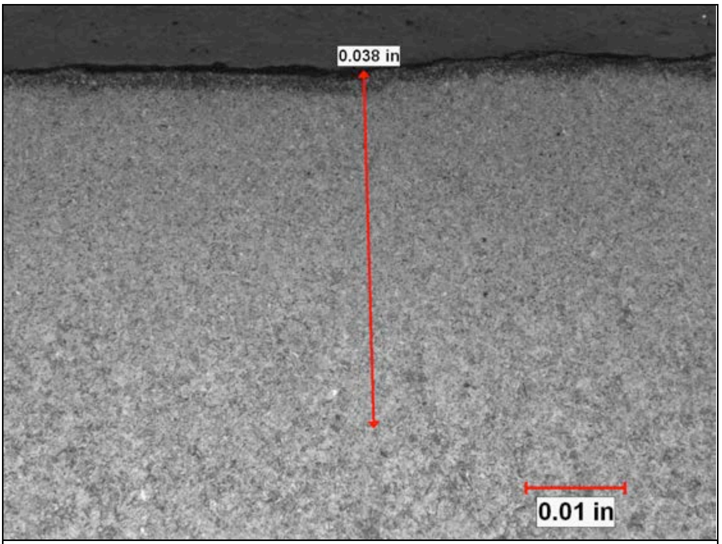

**Photo 10:** Mag: 50X; Etchant: 3% Nital
Chain 4B: Carburized case at same location in Photo 9. Depth of case on “flash” line observed to a depth of .038”.

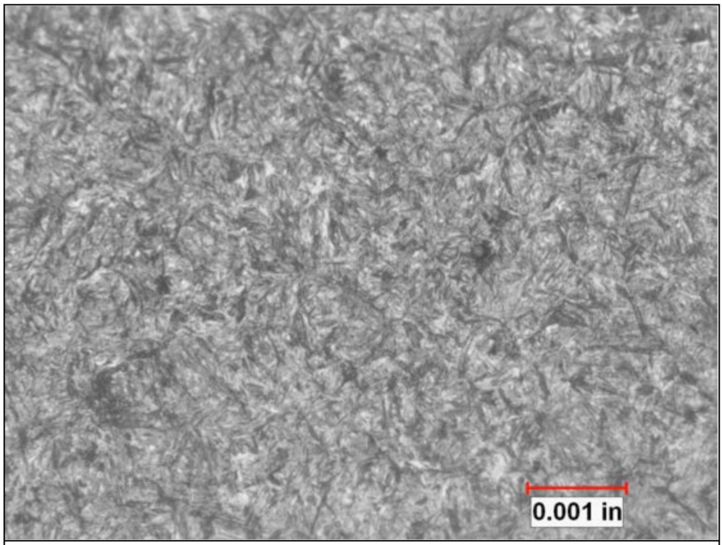

**Photo 11:** Mag: 500X; Etchant: 3% Nital
Chain MCV: The carburized case away from the fracture origin consisted of small amounts of retained austenite in a matrix of tempered martensite. Hardness = 60 HRC

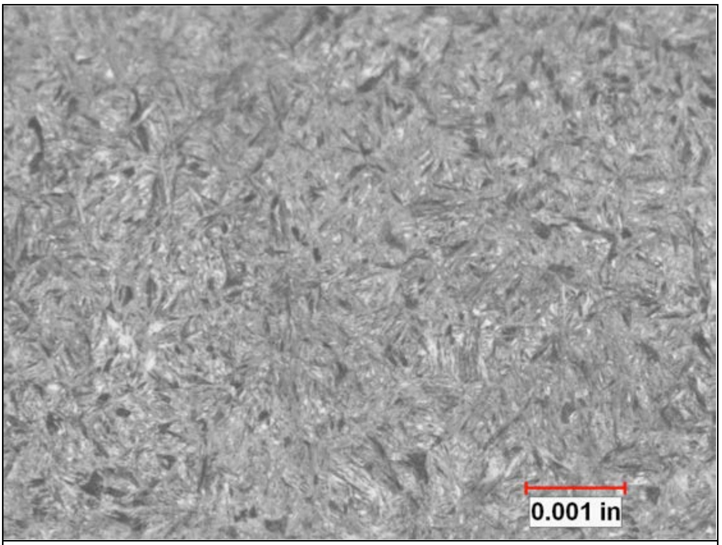

**Photo 12:** Mag: 500X; Etchant: 3% Nital
Chain 4B: The carburized case at the same location consisted of small amounts of retained austenite in a matrix of tempered martensite. Hardness = 59 HRC

## Metallographic Examination

1. Examination of the core of both Chain samples revealed similar microstructures, which consisted of tempered martensite. The boron treated steel used in Chain MCV contributed to increased hardness. (See Photos 13 & 14)
2. The core microstructure of both samples indicates that the two chains were subjected to quench hardening and tempering after carburization of the surface.

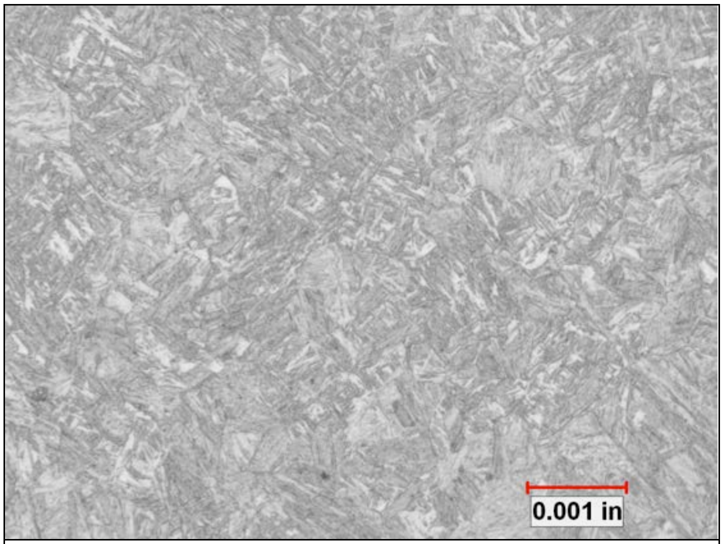

**Photo 13:** Mag: 500X; Etchant: 3% Nital
Chain MCV: The core microstructure consisted of tempered martensite. Hardness = 37 HRC

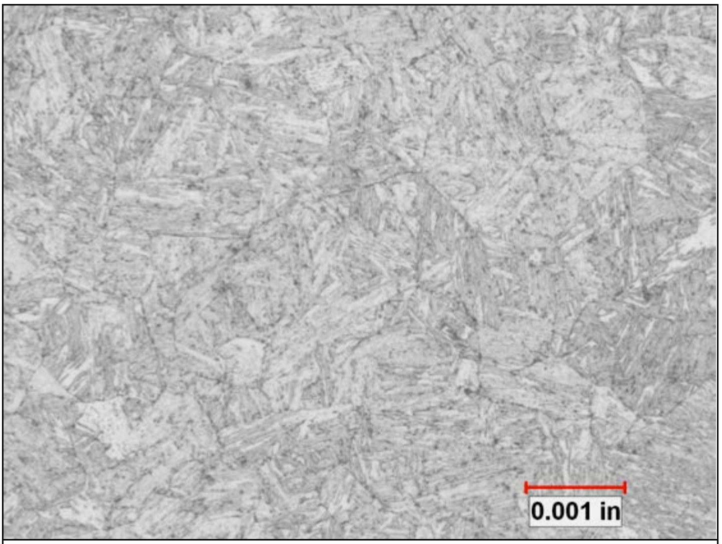

**Photo 14:** Mag: 500X; Etchant: 3% Nital
Chain 4B: The core microstructure consisted of tempered martensite. Hardness = 35 HRC

## Hardness Testing

1. Microhardness testing was performed on full transverse cross sections of both samples at the side surface (trim-line) opposite the fracture location of Chain MCV. The results indicate that the effective case depth of MCV to 50 HRC minimum was .030” and the effective case depth of 4B to 50 HRC minimum was .045”. Sample MCV conformed to the required effective case depth requirement of .030 – .040” as compared to sample 4B, which slightly exceeded the specified requirement of .030 – 040”.
2. Core hardness testing verified that both samples conformed to the specified range of 300 – 400 Brinell.
3. The results are shown in attached Table 1.

## Chemical Testing

1. Chemical test results verified the two chain samples were both manufactured from similar Cr-Mn alloy steel. The steel of chain MCV was boron treated for improved hardenability.
2. The results are shown in attached Table 2.

**Tensile Testing**

1. Tensile test results of core material between the pinholes of the individual chains indicate Chain MCV exhibited increased tensile and yield strength as compared to Chain 4B.
2. The results are shown in attached Table 3.

Respectfully Submitted,

***MSi Testing & Engineering, Inc.*** Reviewed By,

Allan W. Scheive John J. Fruscione

Allan W. Scheive
Senior Metallurgical Engineer

John J. Fruscione
Senior Metallurgical Engineer

AWS/JJF/ E-document

## Table 1 – Microhardness Testing *

| Distance Below Surface, in. | Hardness, HRC (Chain MCV) | Hardness, HRC (Chain 4B) |
|---|---|---|
| .002 | 60 | 55 |
| .005 | 60 | 59 |
| .010 | 60 | 60 |
| .020 | 55 | 57 |
| .030 | 50 ** | 55 |
| .035 | 48 | --- |
| .040 | --- | 53 |
| .045 | --- | 50 ** |
| .055 | --- | 48 |
| Core Hardness, HRC (HBW) *** | 37 37 37 (363) | 35 35 35 (327) |

* Testing performed in accordance with ASTM E384. Knoop values determined using 500g load were converted to approximate HRC values using Table 1 of ASTM E140. ** ECD to 50 HRC minimum. *** Testing performed in accordance with ASTM E18 and converted to HBW in accordance with ASTM A370 Table 2.

## Table 2 – Chemical Testing *

| Element | Chain MCV | Chain 4B |
|---|---|---|
| Carbon | .17 % | .16 % |
| Manganese | 1.11 | .86 |
| Phosphorus | .012 | .018 |
| Sulfur | .019 | .022 |
| Silicon | .20 | .24 |
| Nickel | .05 | .04 |
| Chromium | 1.06 | 1.05 |
| Molybdenum | <.01 | <.01 |
| Copper | .18 | .01 |
| Aluminum | .02 | .02 |
| Titanium | .05 | .06 |
| Boron | .0045 | <.0005 |
| **Steel Grade** | **Similar to 51B20** | **Similar to 5120** |

* Testing performed in accordance with ASTM E415.

## Table 3 – Tensile Testing *

| | Chain MCV | Chain 4B |
|---|---|---|
| Tensile Strength, psi | 201,500 | 168,900 |
| Yield Strength, psi (.2% Offset) | 157,100 | 131,400 |
| % Elongation in 1” (4D) | 14 | 14 |
| % Reduction of Area | 51 | 63 |

* Testing performed in accordance with ASTM A370, E8.