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ANALYSIS AND OPTIMIZATION OF H-13 FORGE STEEL DIE MATERIAL FOR BULK PRODUCTION

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Abstract: The properties of H13 are dependent on the microstructure, the composition, and the heat treatment. The microstructure of H13 steel is composed of a tempered Ti C matrix, with various alloying element carbide precipitates distributed within. These carbides are composed of molybdenum, vanadium, chromium and iron. The size of the carbides varies for each alloying element that composes it. The molybdenum and vanadium carbides tend to be larger in size and clustered together. Carbides, composed of iron and chromium, are distributed evenly and therefore are very fine and do not form clustered colonies. The size of the carbides plays a key role in fracture. The present work discuss the life feasibility of the die by practical way of observing micro structures of bottom die after crack propagation and the hardness levels of heating. The process has been carried out on 1 ton hammer for observation of load impacts on the die.
Key words: H13 die steel, SEM analysis, Durability.

1.0 Introduction: The un-failed die was inspected for cracking in the machined groove where the other die failures had originated. A three-part liquid dye penetrant kit was used for this inspection. The procedure first involves cleaning the sample surface thoroughly with a solvent. Second, the area of interest is masked to minimize dye spreading to irrelevant areas. The dye is then liberally applied to the area of interest and let sit for a minimum of 30 minutes. Third, the dye is wiped thoroughly from all surfaces using a cloth dampened with solvent. Lastly, a developer is applied to the area of interest. The developer will pull the dye out of any notch, crevice, crack, etc. and produce an indication of the defect.

2.0 Objectives

1. Heat treatment and raw materials practices have to observe for die failures.
2. Hardness of this material for gear blank forging dies is 43-47 HRC has to observe.
3. To check the feasibility of vacuum surface hardening techniques.

3.0 Methodology

A list of sample conditions can be verified. Both the failed and un-failed dies (of varying part number) saw various service conditions. All of the failed and un-failed samples were positioned on the bottom during service; and, all die temperatures (that were recorded) were less than 140 degrees Fahrenheit. There was also a discrepancy between the number of parts forged between samples A, B, and E. Samples A and B forged a very small number of parts, whereas sample E forged parts into the thousands.

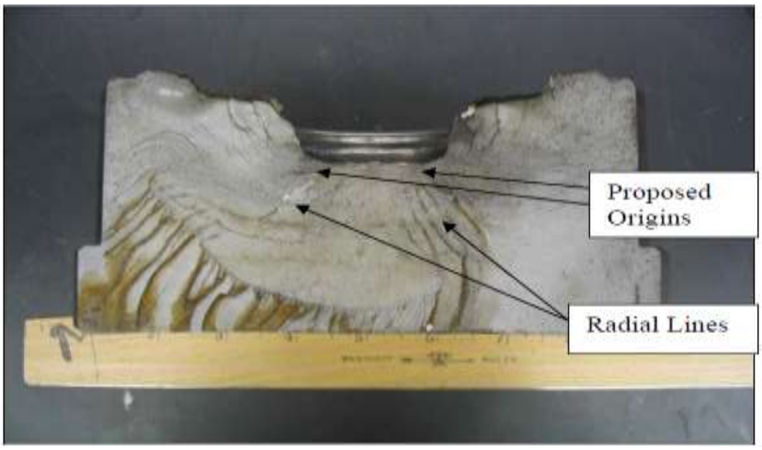
	A	B	C	D	E	F	G	H
Part number	3914	4003	3914	N/A	3914	N/A	3914	N/A
Condition	Failed	Failed	Un-failed	Bar stock	Failed	Bar stock	Failed	Failed
Position	Bottom blocker	Bottom finisher	Bottom Blocker	N/A	Bottom finisher	N/A	Bottom finisher	N/A
Stock	PH	PH	PH	VHT	PH	PH	PH	VHT
Temp @ Failure (^{0}F)	N/A	97	N/A	N/A	137	N/A	135	N/A
# of Parts Forged	40	72	0	N/A	1,124	N/A	N/A	N/A

Die characteristics

The manner in which each of the failed dies fractured was identical. Figure below is a representative photograph of the appearance of the fractured dies. The failures appeared to have started near the center radius of the die and propagated outward.

dies were nearly broken into two pieces by the failures

This observation yielded little information about the cause of failure. Therefore, the failures were propagated using a hammer to allow examination of the fracture surface. The fracture surfaces contained very useful morphologies that enabled conclusions of the origins of failure to be made, Figure Inspection of the fracture surface under the stereomicroscope and with the naked eye revealed no signs of fatigue. The failure appeared to be brittle in nature, which was expected due to its high hardness, and to have occurred in a very few number of cycles. The radial lines on the surface pointed to the source of failure as being near the center radius of the die.



Photograph of die A fracture surface with origins and radial lines marked

Material Evaluation

• Hardness

Marco-hardness readings were taken on a cross-section of each stock material and in numerous places on each received die. This was conducted with a NewAge Indentron Rockwell C hardness tester and a New Age Brinell Tester. Any signs of poor heat treatment or wrong alloy composition would be identified from this testing. Micro-hardness was conducted on three of the samples prepared for microstructural analysis. This test was conducted with a Vickers Micro-Hardness Indenter, 500 Kg load. The intent of this test was to determine the presence of, approximate depth, and hardness of the decarburization layer on the surface of each die. A decarburization layer on the surface would allow for cracks to begin much easier on the surfaces of the dies.

• Metallography

A sample of each die, the vacuum heat treated stock, and the pre-hardened stock were sectioned from the failing region and prepared for microstructural analysis via standard metallographic procedures. A 2% Nital etch was used on all samples. This would reveal any signs of poor heat treatment or other imperfections in the microstructure.

• Chemical Analysis

To ensure that all samples met the manufacturer's requirement of a H13 tool steel alloy, sections were sent to an outside laboratory (Sherry Laboratories) for chemical analysis. The laboratory used optical emissions spectrometry to determine the alloy composition of manganese, phosphorus, silicon, nickel, chromium, molybdenum, copper, and vanadium. A combustion method was used with a Carbon- Sulfur Leco instrument to determine the carbon and sulphur contents of the steel. Finally an inert gas fusion method on a Leco machine was utilized to determine the percent oxygen of the steel.

• Inspection for cracking

The un-failed die, die C, was inspected for cracking in the machined groove where the other die failures had originated. A three-part liquid dye penetrant kit was used for this inspection. The procedure first involves cleaning the sample surface thoroughly with a solvent. Second, the area of interest is masked to minimize dye spreading to irrelevant areas. The dye is then liberally applied to the area of interest and let sit for a minimum of 30 minutes. Third, the dye is wiped thoroughly from all surfaces using a cloth dampened with solvent. Lastly, a developer is applied to the area of interest. The developer will pull the dye out of any notch, crevice, crack, etc. and produce an indication of the defect. To verify the dye penetrant results, die C was also sectioned through the areas of possible cracks. A profile of the possible cracks was then prepared metallographically and observed under a light microscope at various magnifications.

Fracture Toughness Analysis

• Mechanical Properties

The range of hardness in the materials allowed for a comparison to fracture toughness values in the ASM Handbook (Volume 1: Properties and Selection: Irons and Steels). This test was conducted with the hypothesis that when the harder materials are machined, cracks are initiated. Also that the harder material has less resistance to crack propagation.

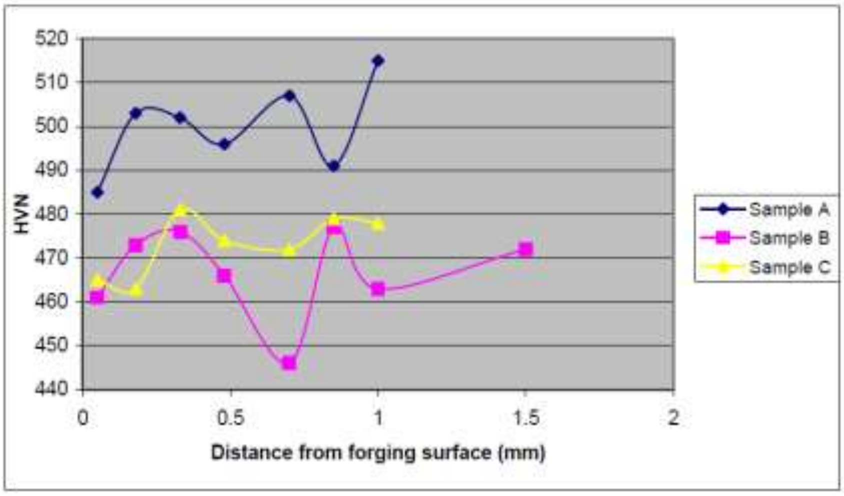
Results and Discussion

Material Evaluation : The specified hardness, as determined by Walker Forge, Inc., of the pre-hardened stock dies is 43 – 47 HRC. All of the samples tested were within this range. Testing on the vacuum heat treated stock sample and failed die showed hardness values of approximately 41-44 HRC. Table 4 shows there is little difference in hardness between all of the samples Therefore, the cause of failure does not appear to lie within heat treating problems.

Macro-hardness results met specifications

sample	Specification	HRC(+/-1)	BHN
A	43-47	46	415-429
B	43-47	45	415-429
C	43-47	44.5	415-429
D(VHT stock)	41-44	41	401-415
E	43-47	44.9	415-429
F(PH stock)	43-47	47	429-444
G	43-47	45	415-429
H(VHT die)	41-44	43	415-429

Micro-hardness measurements were then taken on several of the pre-hardened dies (dies A, B, and C) at the forging surface in order to determine the presence of decarburization or work hardening. Either of these two phenomenon would have a dramatic effect on the surface properties of the dies. No signs of any defects were found on any of the samples as can be seen by Figure.



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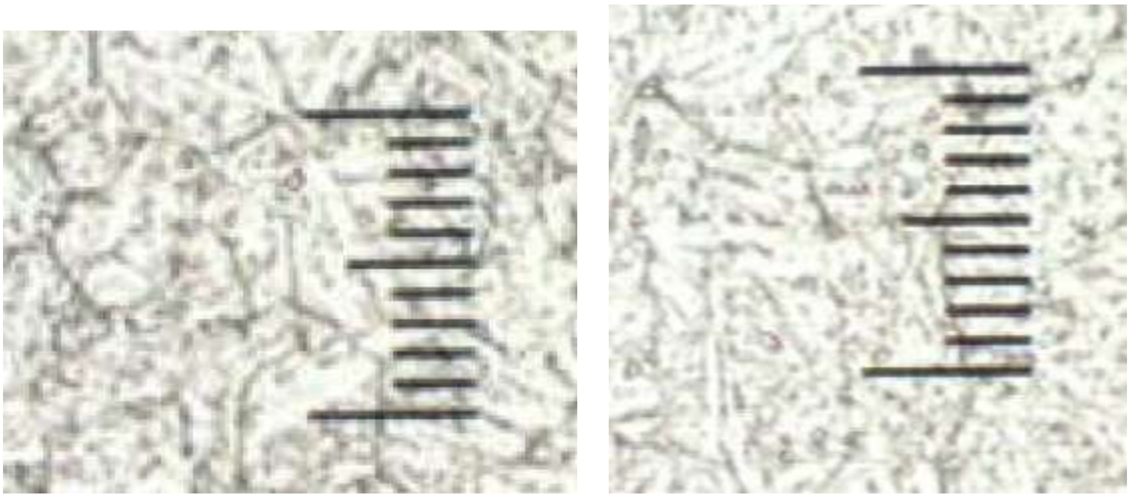
Micro-hardness traverse measurements yielded no signs of defects
Microstructural comparison was performed between all samples. The microstructures of all specimens were nearly identical; however, the microconstituents of the vacuum heat treated material appeared slightly finer than the pre-hardened material. This finer microstructure was thought to denote the difference in heat treatments and/or alloying elements.

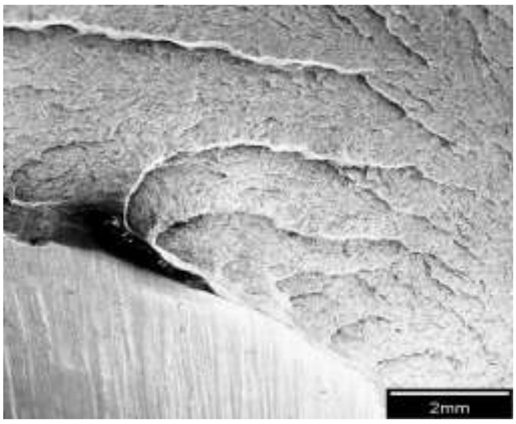


Micrograph of die A & H revealing micro constituents present (2% Nital, Scale bar 20 μm).
In order to measure the alloying elements present and ensure compliance with specifications, a section of each sample was sent to an outside laboratory for chemical analyses. Table reveals all the dies and stocks were within the chemical specifications, so the finer microstructure in sample D is not caused by difference in alloying elements. The slight differences were caused by the two types of heat treatment, induction and vacuum heat treating.

Chemistry results of samples tested meet specification

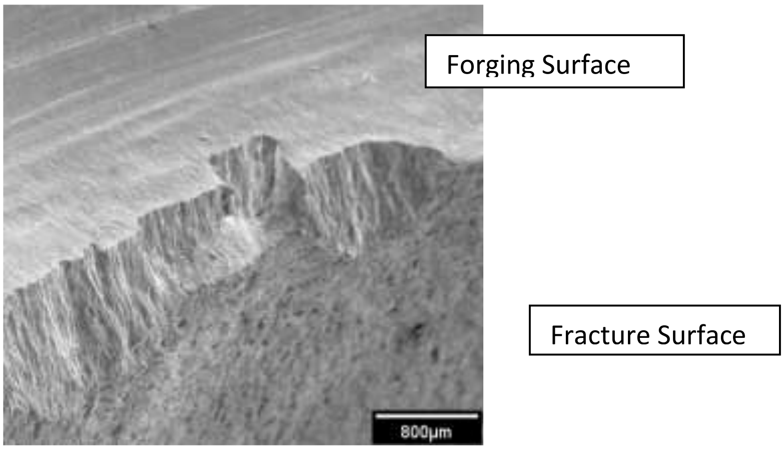
Element	Specification	Sample A	Sample B	Sample C	Sample D	Sample E
Carbon	0.32-0.45	0.40	0.39	0.39	0.44	0.43
Manganese	0.20-0.50	0.33	0.32	0.36	0.42	0.42
Phosphorus	≤ 0.025	0.012	0.012	0.014	0.017	0.02
Sulfur	≤0.005	<0.005	<0.005	<0.005	<0.005	0.016
Silicon	0.80-1.20	1.03	0.97	1.03	1.09	1.10
Nickel	N/A	0.17	0.10	0.20	0.14	0.12
Chromium	4.75-5.50	5.43	5.47	5.49	5.56	5.46
Molybdenum	1.10-1.75	1.18	1.23	1.25	1.39	1.29
Copper	N/A	0.12	0.17	0.10	0.16	0.13
Vanadium	0.80-0.20	0.94	0.89	0.98	1.06	1.03
Oxygen	N/A	<0.005	0.009	<0.005	<0.005	0.005

Fracture Surface Analysis: Scanning electron microscopy was performed on two of the failed dies, A and E, to determine the mode(s) of failure and the precise initiation points. It was not possible to find the exact initiation point of each failure due to the large number of origins and some post-failure damage. However, some large oxide inclusions were found near the center radius of the die where the failure was believed to have initiated, Figure. There were river marks radiating out from these oxides which revealed they contributed in some manner to the initiation or propagation of the failure.



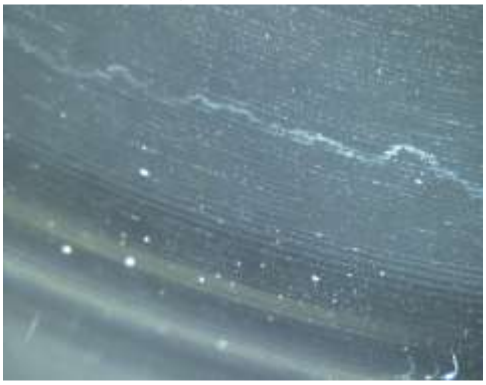
Micrograph shows presence of oxide inclusion near failing radius.

The fracture surface was characterized to be a brittle type failure with no signs of fatigue, the failure mode was found to be low cycle, high stress fatigue from the morphology of the fracture surface. Due to the extreme forces applied to the dies, the fracture propagated to complete failure in very few cycles.



Micrograph illustrates forging/fracture surface interface on die E.

Machining Defects: During SEM observation, the presence of large machining grooves was found near the failing radiuses of the dies.



Stereomicroscopic image shows possible crack.

To find whether or not this or any cracks existed in the die, a dye penetrant test was used. The test revealed no signs of cracks on the machined surface.

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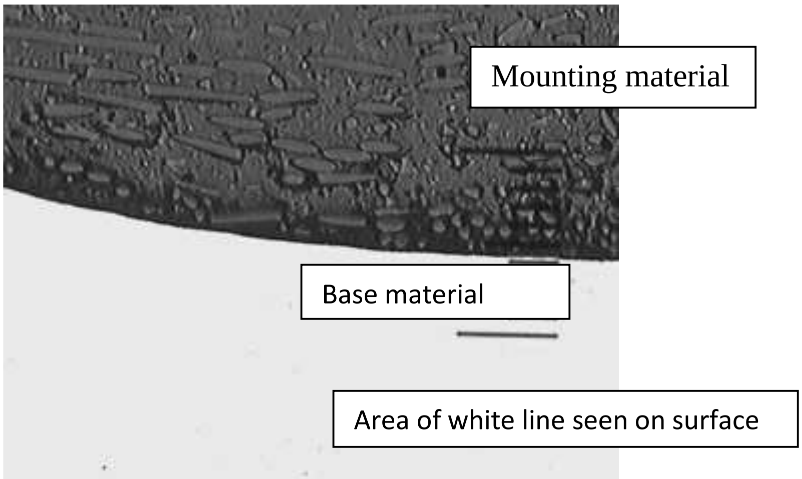
Cracks would appear as red lines on the white background

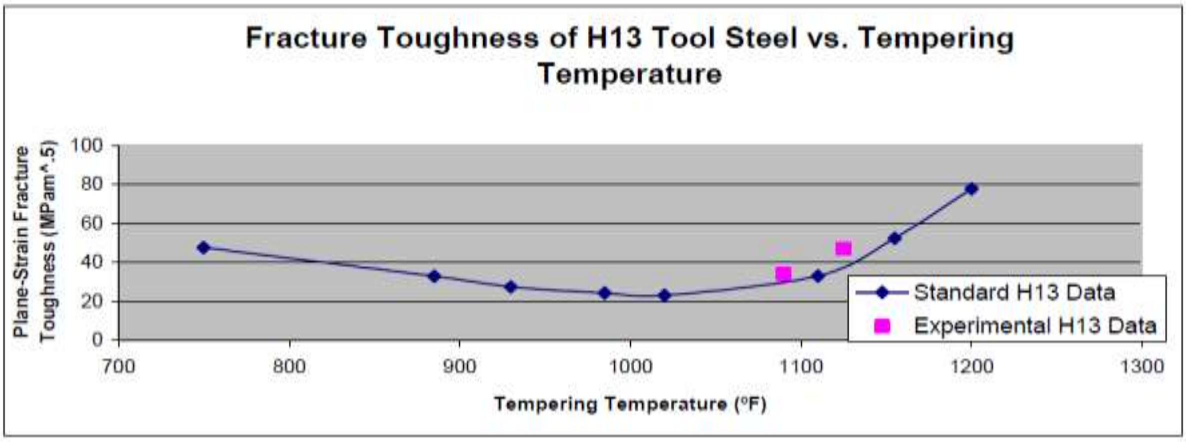
The die was next sectioned through the unknown line and prepared metallographically. This determined the depth of the scratch and also fully ruled out the presence of any type of crack. Figure shows that no signs of cracks, scratches or even deep grooves exist where the white line was. The line was then determined to be a light scratch on the surface of the die, possibly from handling.



Micrograph shows no signs of any large surface defects were found, scale bar 200 µm

Fracture Toughness Analysis : Fracture toughness testing performed has shown the vacuum heat treated stock to have a higher fracture toughness value, 47 MPa√m. The fracture toughness value for the pre-hardened stock was 34 MPa√m.

The relationship between tempering temperatures and longitudinal (plane strain)



The graphical relationship between fracture toughness and tempering temperature for H13 steel are plotted for standard and experimental data.

CONCLUSIONS:

The material evaluation of the pre-hardened and vacuum heat treated materials revealed no signs of any defects. Hardness, chemistry, and microstructure of each failed die and stock sample met the required specifications. Stereomicroscope and SEM observation of the fracture surfaces yielded valuable information about the failures. It was clear that no signs of fatigue were present on the dies and the failures occurred in a brittle manner.

The use of dye penetrant and sectioning through the failing radius showed that no cracks or deep machining grooves existed. Current fracture toughness testing has shown the vacuum heat treated stock to have a greater value than the pre-hardened stock. This is a critical result due to the importance of fracture toughness in a forging operation. Indentations and wear are commonalities to dies in forging operations.

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