

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594



October 31, 2018

MATERIALS LABORATORY FACTUAL REPORT

18-091

A. ACCIDENT INFORMATION

Place : Goodyear, Arizona
Date : June 4, 2017
Vehicle : Titan T51, N51FB
NTSB No. : WPR17LA121
Investigator : Elliott Simpson

B. COMPONENTS EXAMINED

Prop (idler gear) and pinion (drive) gear segments.

C. DETAILS OF THE EXAMINATION

Figure 1 shows the as-received gear pieces prior to cutting while figure 2 shows locations where the gears were cut in preparation for cross-sectioning. As can be seen in figure 5 (drive gear) and figure 7 (idler gear) the teeth in the cross-section of the drive gear appear undamaged while the teeth in the cross-section of the idler gear are deformed and damaged as was evident in the as-received images in figures 1 and 2. Figure 3 shows the actual drive gear shaft on the left side of the image while on the right is the same gear shaft sectioned. The yellow arrow in the image points to the piece that was received by the Materials Laboratory for testing. Figure 4 is a representative image showing a partially disassembled gear reduction drive gearbox with various internal and external components labeled.

The cut gear sections were subsequently mounted for microstructural analysis and micro-hardness testing. The polished surfaces were etched with 2% nital etchant to reveal the micro-structure along with case-hardening depth information. Figure 5 is an overlaid hardness indents location image on an etched cross-section image revealing the microstructure of the drive gear. The numbered red boxes represent areas where higher magnification images were taken. Area 1 is at the tooth edge while area 2 is the core and area 3 is the inside diameter (ID) edge of the gear. The images in figure 6 are micrographs at 100X, 200X and 500X of the drive gear at the locations indicated in figure 5. Figure 7 is an overlaid hardness indents location image on an etched cross-section image revealing the microstructure of the idler gear. The numbered red boxes represent areas where higher magnification images were taken. Area 1 is at the tooth edge while area 2 is the core and area 3 is the inside diameter edge of the gear. The images in figure 8 are micrographs at 100X, 200X and 500X of the idler gear at locations indicated in figure 7.

The cross-sectioned mounts were repolished to remove the etched surface for subsequent micro-hardness testing. Knoop hardness (HK) diamond indents were measured and converted into Rockwell C (HRC) values.¹ Locations of the indents are shown in figures 5 (drive gear) and 7 (idler gear). Hardness measurements were made in primarily three locations. The effective case depth of the gears could not be determined, since at all locations tested (except for the damaged tooth edge on the idler gear), the hardened case was measured at less than 50 HRC. Therefore, the total case depth measurements from the graphs in tables 1 – 7 are listed below:

<u>Gear – Location</u>	<u>Total Case Depth (inches from surface)</u>
Drive Gear – ID edge	0.033
Drive Gear – edge between teeth	0.029
Drive Gear – tooth edge	0.034
Idler Gear – ID edge	0.032
Idler Gear – edge between teeth	0.025
Idler Gear – tooth edge area 1	0.035*
Idler Gear – tooth edge area 2	0.043*

* Inaccurate result due to the tooth surface damage and the graph shape.

Maximum and minimum hardness values are listed in tables 1-7.

Edward J. Komarnicki
Engineering Technician

¹ ASTM E140-12^{e1}. Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb. ASTM International, West Conshohocken, PA, 2012.

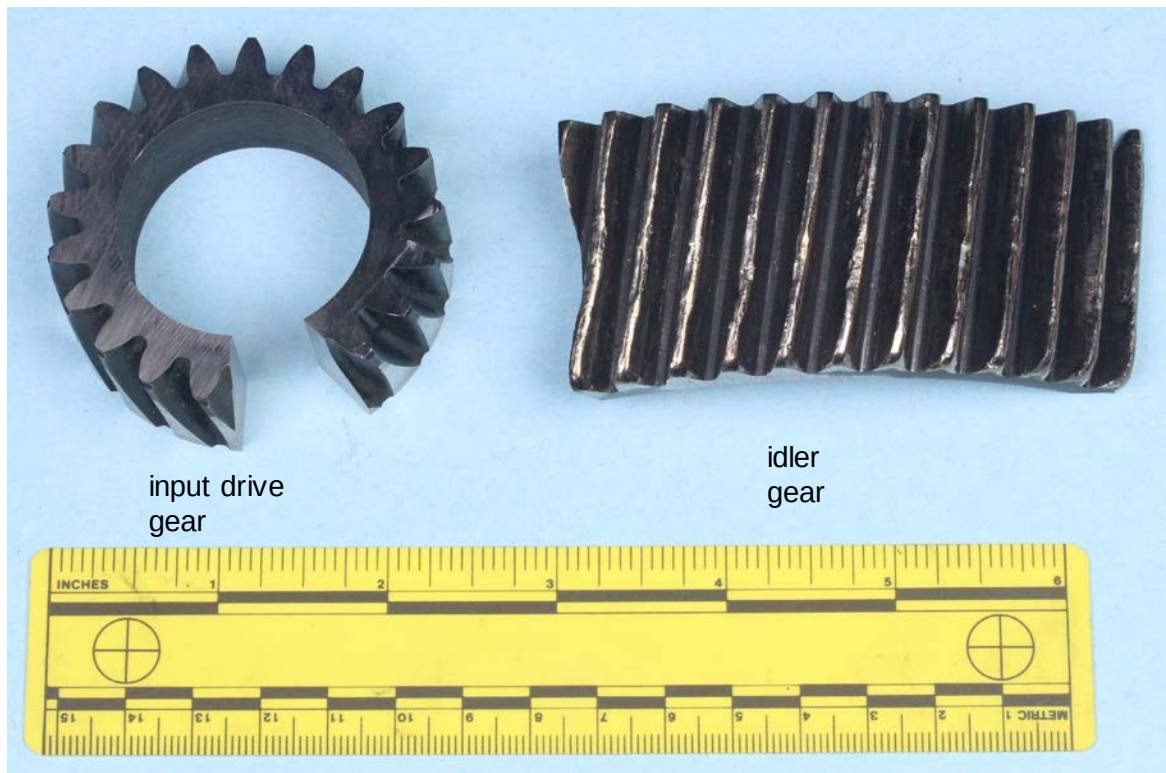


Figure 1. The as-received drive and idler gear pieces.

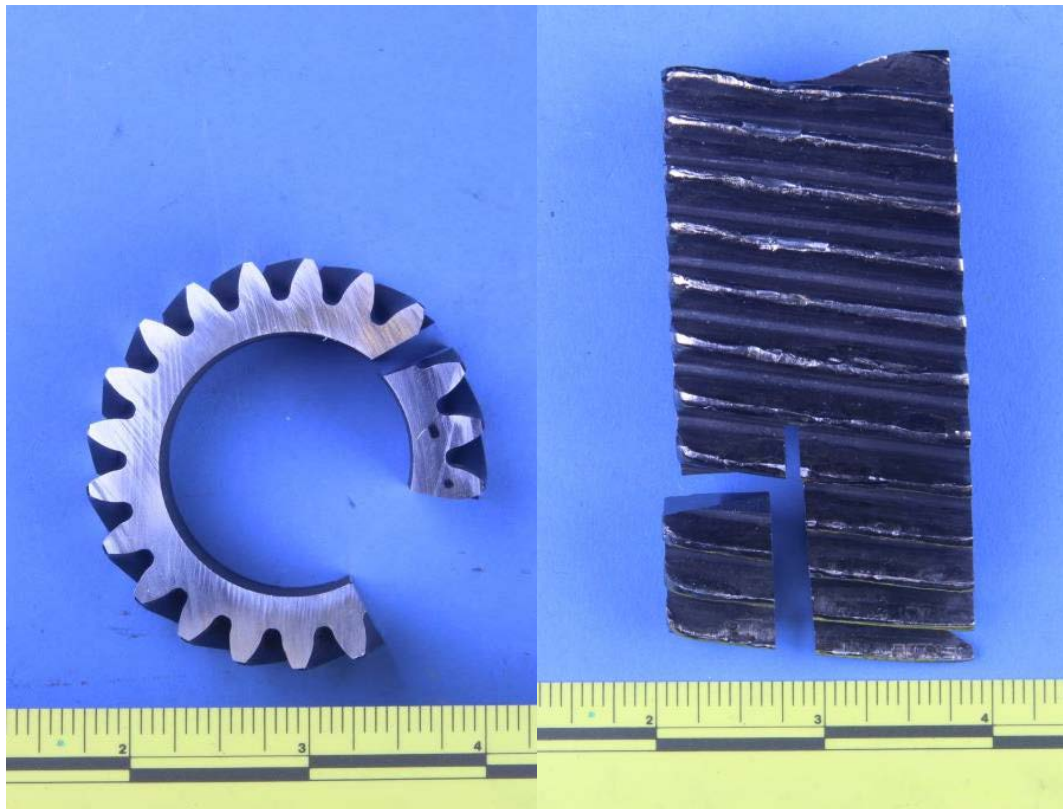


Figure 2. Location of sectioning for further NTSB Materials Laboratory examination.



Figure 3. Actual drive gear with arrow pointing to segment received for testing.

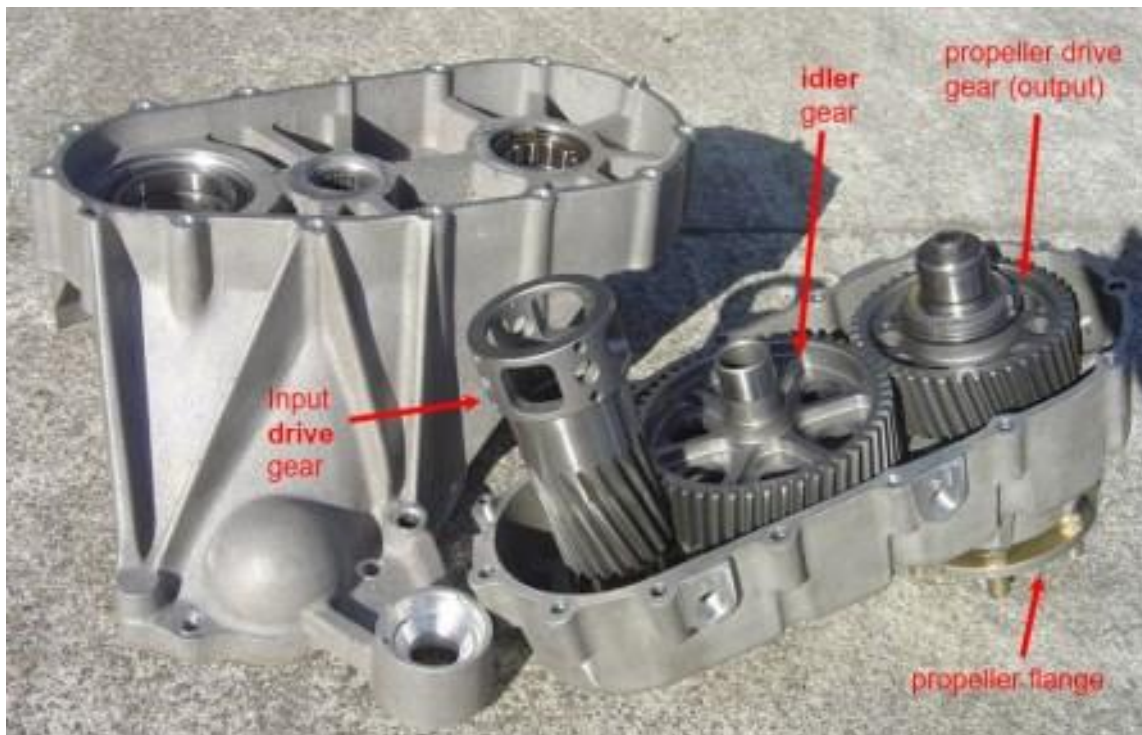


Figure 4. A partially disassembled example gear reduction drive gearbox casing showing the various internal gears.

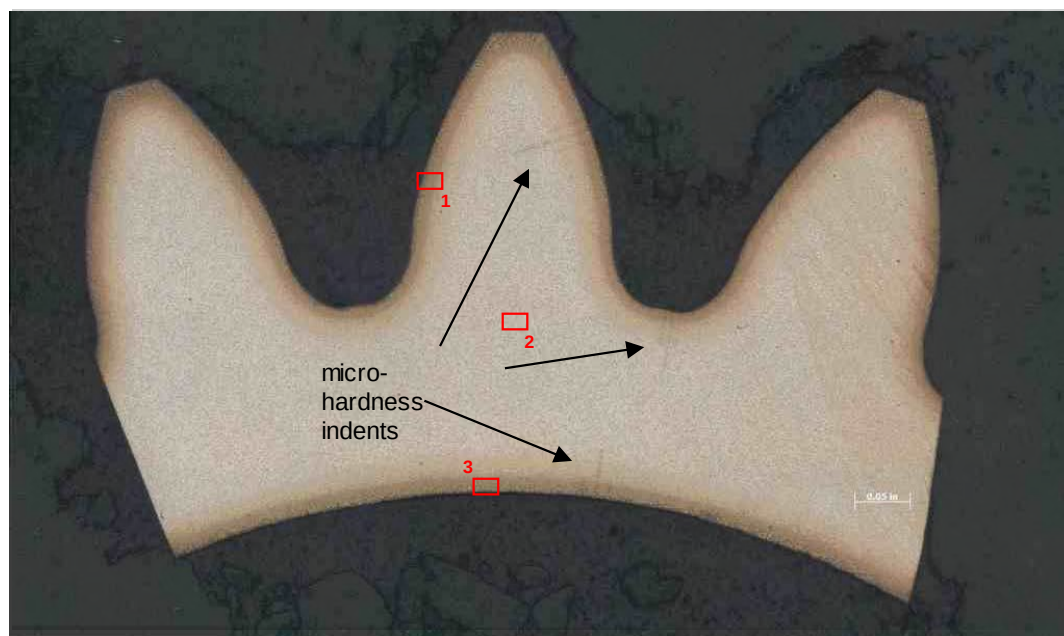


Figure 5. Overlaid image of a section of the drive gear teeth showing locations of micro-hardness indents and higher magnification microstructure image locations (red boxes) (2% nital etch).

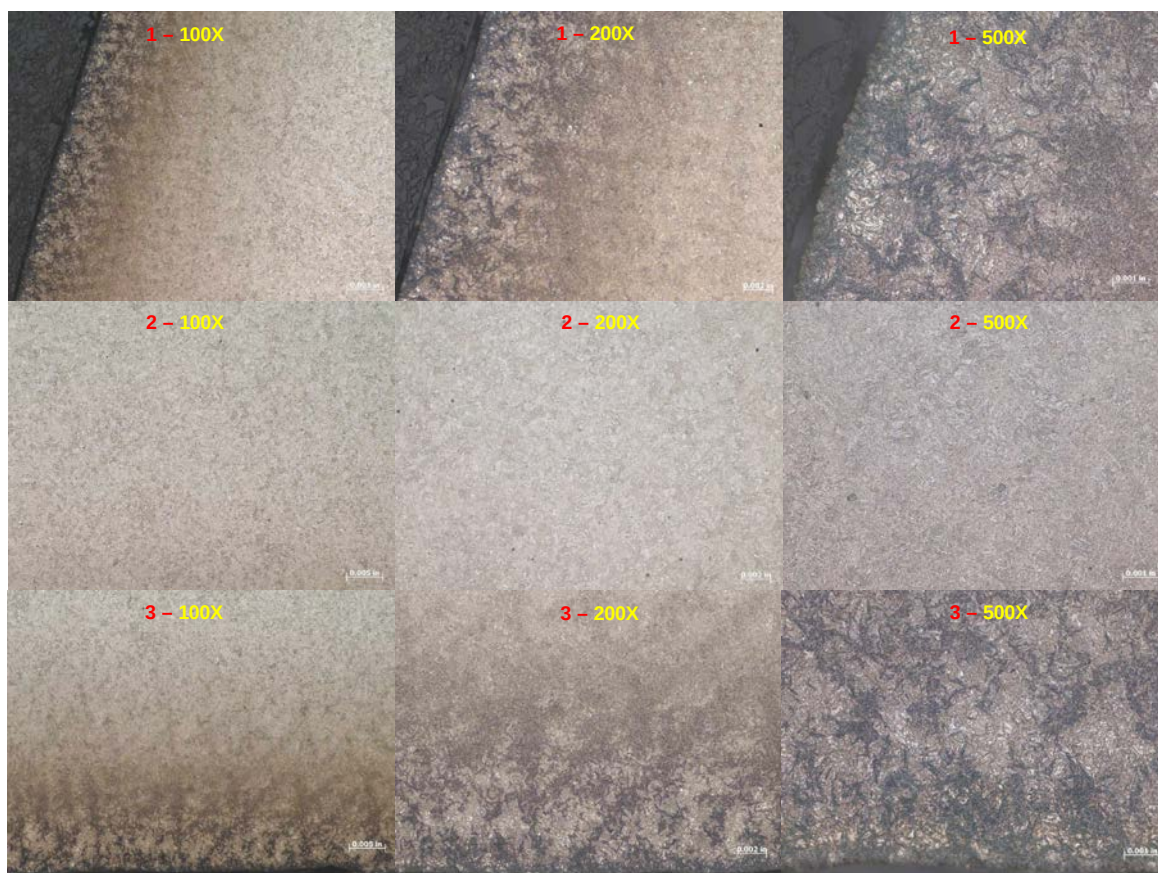


Figure 6. Micrographs of various areas on the drive gear (2 % nital etch).

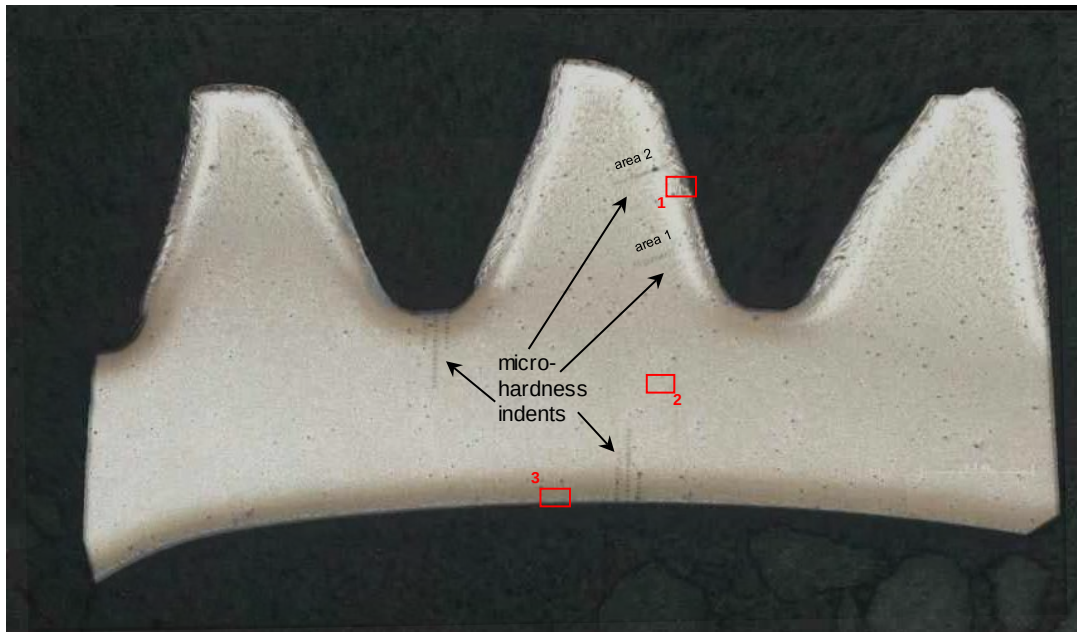


Figure 7. Overlaid image of a section of the idler gear teeth showing locations of micro-hardness indents and higher magnification microstructure image locations (red boxes) (2% nital etch).

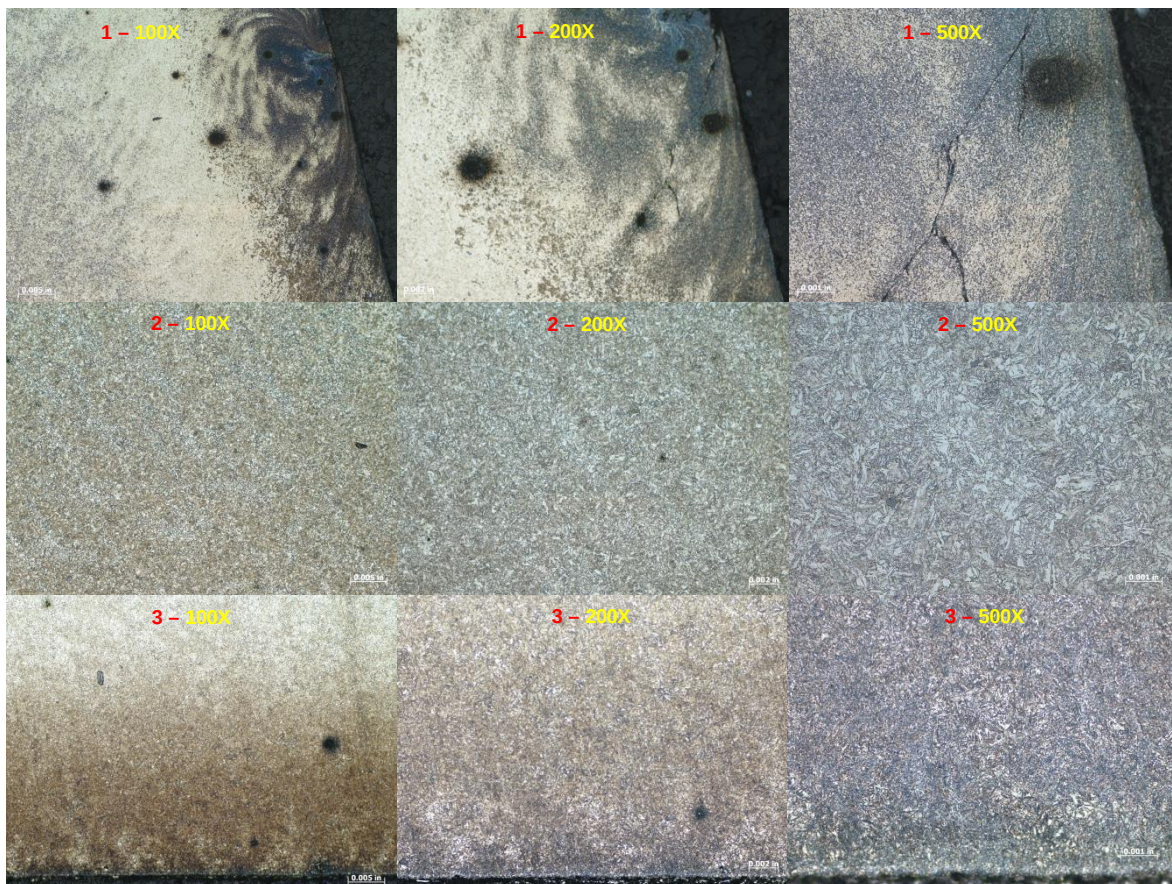


Figure 8. Micrographs of various areas on the idler gear (2% nital etch).

<u>Drive Gear ID edge</u>			
Readings	Distance	Hardness (HK)	HRC
1	0.0021	523.0	48.8
2	0.0041	532.0	49.4
3	0.0061	532.0	49.4
4	0.0081	532.0	49.4
5	0.0101	528.0	49.1
6	0.0121	524.0	48.9
7	0.0141	507.0	47.8
8	0.0161	498.0	47.2
9	0.0181	492.0	46.8
10	0.0201	474.0	45.6
11	0.0221	473.0	45.5
12	0.0241	463.0	44.8
13	0.0261	455.0	44.2
14	0.0281	443.0	43.3
15	0.0301	431.0	42.4
16	0.0321	424.0	41.8
17	0.0341	413.0	40.9
18	0.0363	409.0	40.6
19	0.0381	409.0	40.6
20	0.0406	408.0	40.5
max:		532.0	49.4
min:		408.0	40.5

HK Standard Verification 500 gf

Readings	Hardness
1	536.0
2	533.0
3	534.0
Average =	534.4
Std (area 5) Avg =	536.5

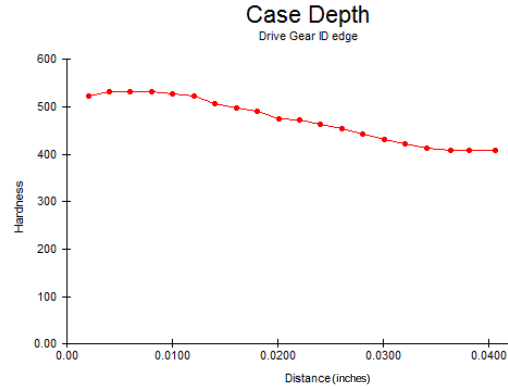


Table 1. Drive gear ID edge micro-hardness readings (HKN 500).

<u>Drive Gear edge between teeth</u>			
Readings	Distance	Hardness (HK)	HRC
1	0.0015	509.0	47.9
2	0.0026	516.0	48.4
3	0.0045	531.0	49.3
4	0.0060	524.0	48.9
5	0.0070	527.0	49.0
6	0.0087	527.0	49.0
7	0.0108	513.0	48.2
8	0.0119	505.0	47.6
9	0.0135	492.0	46.8
10	0.0150	487.0	46.4
11	0.0165	475.0	45.7
12	0.0180	472.0	45.4
13	0.0195	468.0	45.1
14	0.0209	455.0	44.2
15	0.0226	446.0	43.5
16	0.0239	441.0	43.2
17	0.0255	436.0	42.8
18	0.0269	435.0	42.7
19	0.0284	425.0	42.0
20	0.0300	420.0	41.5
21	0.0315	426.0	42.0
22	0.0329	423.0	41.7
23	0.0360	424.0	41.8
24	0.0390	426.0	42.0
25	0.0419	420.0	41.5
26	0.0449	414.0	41.0
27	0.0480	414.0	41.0
28	0.0510	419.0	41.4
29	0.0540	418.0	41.3
30	0.0569	420.0	41.5
max:		531.0	49.3
min:		414.0	41.0

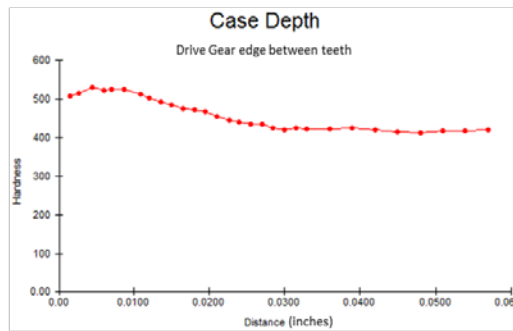


Table 2. Drive gear edge between teeth micro-hardness readings (HKN 500).

<u>Drive Gear tooth edge</u>			
Readings	Distance	Hardness (HK)	HRC
1	0.0016	514.0	48.2
2	0.0030	541.0	49.9
3	0.0046	541.0	49.9
4	0.0061	533.0	49.4
5	0.0076	537.0	49.7
6	0.0091	536.0	49.6
7	0.0107	532.0	49.4
8	0.0121	525.0	49.0
9	0.0136	523.0	48.8
10	0.0151	509.0	47.9
11	0.0166	507.0	47.8
12	0.0181	499.0	47.3
13	0.0196	490.0	46.7
14	0.0211	487.0	46.4
15	0.0227	473.0	45.5
16	0.0241	462.0	44.7
17	0.0256	461.0	44.7
18	0.0271	451.0	43.9
19	0.0284	448.0	43.7
20	0.0301	437.0	42.9
21	0.0316	427.0	42.1
22	0.0331	425.0	42.0
23	0.0347	427.0	42.1
24	0.0362	420.0	41.5
25	0.0376	422.0	41.6
26	0.0405	423.0	41.7
27	0.0436	414.0	41.0
28	0.0468	415.0	41.1
29	0.0496	417.0	41.2
30	0.0534	412.0	40.8
31	0.0566	418.0	41.3
32	0.0606	415.0	41.1
33	0.0646	407.0	40.4
34	0.0686	411.0	40.7
35	0.0723	408.0	40.5
max:		541.0	49.9
min:		407.0	40.4

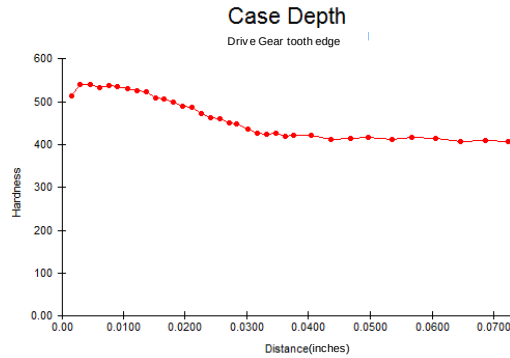


Table 3. Drive gear tooth edge micro-hardness readings (HKN 500).

<u>Idler Gear ID edge</u>			
Readings	Distance	Hardness (HK)	HRC
1	0.0016	421.0	41.6
2	0.0031	428.0	42.1
3	0.0046	432.0	42.5
4	0.0061	434.0	42.7
5	0.0076	434.0	42.7
6	0.0091	430.0	42.3
7	0.0105	426.0	42.0
8	0.0121	426.0	42.0
9	0.0135	423.0	41.8
10	0.0151	412.0	40.8
11	0.0165	409.0	40.6
12	0.0181	403.0	40.1
13	0.0196	395.0	39.4
14	0.0211	387.0	38.6
15	0.0226	376.0	37.6
16	0.0241	371.0	37.1
17	0.0255	364.0	36.4
18	0.0271	354.0	35.3
19	0.0285	344.0	34.2
20	0.0300	338.0	33.5
21	0.0331	336.0	33.2
22	0.0361	328.0	32.3
23	0.0390	326.0	32.0
24	0.0421	319.0	31.1
25	0.0450	324.0	31.8
26	0.0490	318.0	30.9
27	0.0530	316.0	30.7
28	0.0570	312.0	30.1
29	0.0610	307.0	29.4
30	0.0650	309.0	29.7
max:		434.0	42.7
min:		307.0	29.4

HK Standard Verification 500 gf

Readings	Hardness
1	523.0
2	533.0
3	535.0
Average =	530.3
Std (area 5) Avg =	536.5

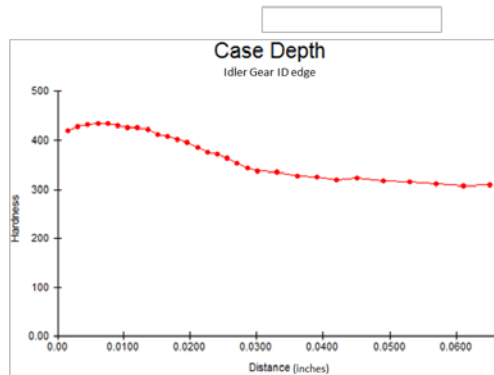


Table 4. Idler gear ID edge micro-hardness readings (HKN 500).

Idler Gear edge between teeth

Readings	Distance	Hardness (HK)	HRC
1	0.0028	426.0	42.0
2	0.0031	432.0	42.5
3	0.0046	432.0	42.5
4	0.0061	430.0	42.3
5	0.0076	425.0	41.9
6	0.0091	418.0	41.3
7	0.0106	415.0	41.1
8	0.0121	406.0	40.4
9	0.0127	409.0	40.6
10	0.0151	395.0	39.3
11	0.0166	380.0	38.0
12	0.0181	374.0	37.4
13	0.0196	369.0	36.9
14	0.0211	352.0	35.1
15	0.0232	344.0	34.2
16	0.0241	333.0	32.9
17	0.0252	332.0	32.7
18	0.0271	336.0	33.3
19	0.0286	331.0	32.7
20	0.0301	338.0	33.5
21	0.0331	333.0	32.9
22	0.0354	337.0	33.3
23	0.0391	328.0	32.3
24	0.0416	329.0	32.4
25	0.0451	327.0	32.2
26	0.0491	320.0	31.3
27	0.0531	319.0	31.2
28	0.0571	314.0	30.5
29	0.0611	314.0	30.5
30	0.0651	314.0	30.5
max:		432.0	42.5
min:		314.0	30.5

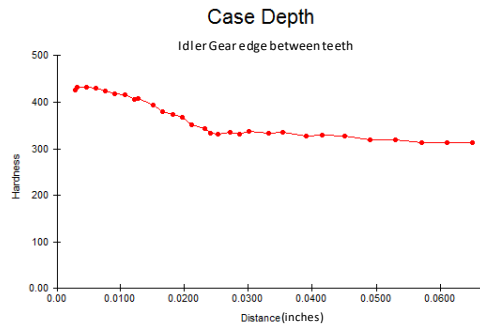


Table 5. Idler gear edge between teeth micro-hardness readings (HKN 500).

Idler Gear tooth edge - area 1

Readings	Distance	Hardness (HK)	HRC
1	0.0016	411.0	40.7
2	0.0031	623.0	54.6
3	0.0041	520.0	48.6
4	0.0061	545.0	50.2
5	0.0076	500.0	47.3
6	0.0091	462.0	44.7
7	0.0106	468.0	45.1
8	0.0121	485.0	46.4
9	0.0127	528.0	49.1
10	0.0151	575.0	51.9
11	0.0172	612.0	54.0
12	0.0181	604.0	53.5
13	0.0196	605.0	53.6
14	0.0211	585.0	52.5
15	0.0232	562.0	51.2
16	0.0243	558.0	51.0
17	0.0253	540.0	49.9
18	0.0271	522.0	48.7
19	0.0286	488.0	46.5
20	0.0301	461.0	44.7
21	0.0325	423.0	41.7
22	0.0354	397.0	39.5
23	0.0391	400.0	39.8
24	0.0419	385.0	38.4
25	0.0451	384.0	38.3
26	0.0491	369.0	36.9
27	0.0531	379.0	37.9
28	0.0571	376.0	37.6
29	0.0611	382.0	38.2
30	0.0651	369.0	36.9
max:		623.0	54.6
min:		369.0	36.9

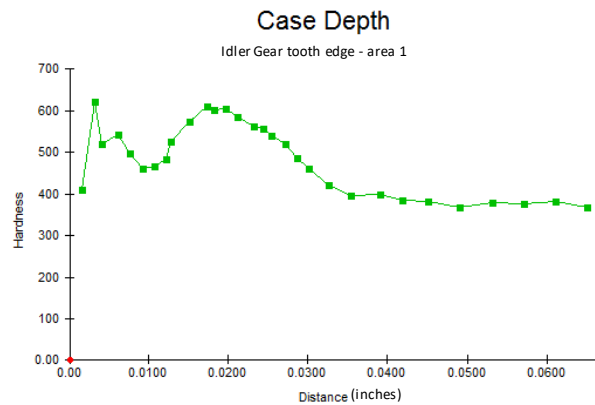


Table 6. Idler gear tooth edge micro-hardness readings in area 1 (HKN 500).

Idler Gear tooth edge - area 2

Readings	Distance	Hardness (HK)	HRC
1	0.0017	365.0	36.5
2	0.0020	426.0	42.0
3	0.0023	448.0	43.7
4	0.0035	460.0	44.6
5	0.0040	478.0	45.8
6	0.0039	483.0	46.2
7	0.0056	531.0	49.3
8	0.0060	553.0	50.7
9	0.0065	556.0	50.9
10	0.0075	593.0	53.0
11	0.0080	597.0	53.2
12	0.0085	623.0	54.6
13	0.0094	593.0	53.0
14	0.0100	558.0	51.0
15	0.0105	590.0	52.8
16	0.0115	625.0	54.7
17	0.0120	647.0	55.9
18	0.0125	627.0	54.8
19	0.0135	623.0	54.6
20	0.0156	604.0	53.6
21	0.0175	601.0	53.4
22	0.0196	600.0	53.4
23	0.0215	604.0	53.5
24	0.0235	597.0	53.2
25	0.0256	586.0	52.6
26	0.0275	560.0	51.1
27	0.0295	537.0	49.7
28	0.0315	520.0	48.6
29	0.0336	496.0	47.1
30	0.0355	482.0	46.1
31	0.0376	466.0	45.0
32	0.0395	462.0	44.7
33	0.0415	442.0	43.3
34	0.0441	413.0	40.9
35	0.0471	400.0	39.9
36	0.0500	396.0	39.5
37	0.0530	394.0	39.2
38	0.0561	399.0	39.7
39	0.0591	409.0	40.6
40	0.0621	406.0	40.4

max: 647.0 55.9

min: 365.0 36.5

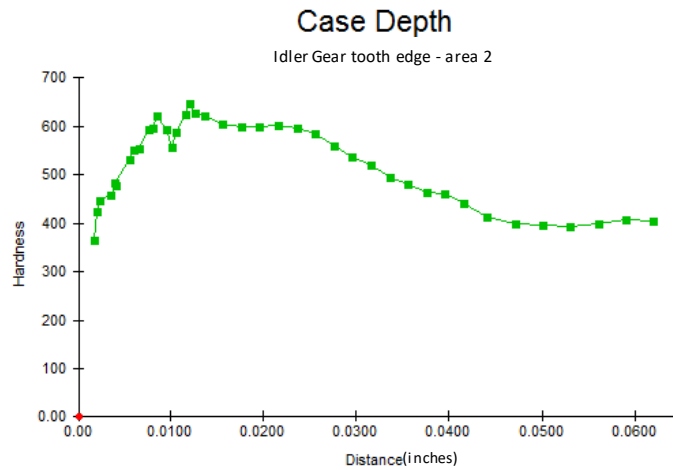


Table 7. Idler gear tooth edge micro-hardness readings in area 2 (HKN 500).