Fatigue Behaviour, Monotonic Properties

and

Microstructural Data

for

AISI 1050M Induction Surface Hardened Steel

(Iteration No. 5)

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SUMMARY

The required chemical analysis, microstructural data, mechanical properties, cyclic stress-strain data and strain-controlled fatigue data for AISI 1050M Induction Surface Hardened steel (Iteration # 5) have been obtained. The material was provided by the American Iron and Steel Institute (AISI) in the form of metal bars. These bars were machined into smooth axial fatigue specimens. A monotonic tensile test was performed to measure yield strength, tensile strength and reduction of area. Nineteen specimens were fatigue tested in laboratory air at room temperature to establish a strain-life curve.

INTRODUCTION

This report presents the results of tensile and fatigue tests performed on a group of 20 AISI 1050M Induction Surface Hardened steel samples. The material was provided by the American Iron and Steel Institute.

The objectives of this investigation were to obtain a chemical analysis, and the microstructural data, mechanical properties, cyclic stress-strain data and strain-life tests requested by the AISI bar group.

EXPERIMENTAL PROCEDURE

Specimen Preparation

The material for the study was received in the form of bars. Smooth cylindrical fatigue specimens, shown in Figure 1, were machined from the metal bars. The gauge sections of the fatigue specimens were mechanically polished in the loading direction using 240, 400, 500, and 600 emery paper. After polishing, a thin band of M-coat D acrylic coating was applied along the central gauge section. The purpose of the M-coat D application was to prevent scratching of the smooth surface by the knife edges of the strain extensometer, thus reducing the incidence of knife-edge failures. In total, 19 fatigue data points were generated.

Test Equipment and Procedure

A monotonic tension test was performed to determine the yield strength, the tensile strength, the percent of elongation and the percent reduction of area. Hardness tests were performed on the surface of three fatigue specimens using a Rockwell C scale. The hardness measurements were repeated three times for each specimen and the average value was recorded.

All fatigue tests were carried out in a laboratory environment at approximately 25 °C using an MTS servo-controlled closed loop electrohydraulic testing machine. A process control computer, controlled by FLEX software [1] was used to output constant strain and stress amplitudes in the form of a sinusoidal wave.

Axial, constant amplitude, fully reversed (R=-1) strain-controlled fatigue tests were performed on smooth specimens. The stress-strain limits for a given cycle of each specimen were recorded at logarithmic intervals throughout the test via a peak reading oscilloscope. Failure of a specimen was defined as a 50 percent drop in tensile peak load from the peak load observed at one half the expected specimen life. For fatigue lives greater than 100,000 reversals, the specimens were tested in stress-control once the stress-strain loops had stabilized. For the stress-controlled tests, failure was defined as the separation of the smooth specimen into two pieces. For strain-controlled tests the loading frequency varied from 0.03 Hz to 5 Hz while in stress-controlled tests the frequency used was up to 30 Hz.

The first reversal of each fatigue test was recorded on an x-y plotter, allowing the elastic modulus (E) and the monotonic yield strength to be determined.

RESULTS

A) Microstructural Data

Figure 2 presents the **Martensite** microstructure of AISI AISI 1050M Induction Surface Hardened steel. A type A inclusion rate of $\frac{1}{2}$ was obtained based on the severity level number according to ASTM E45 method A. Inclusions of types B, C, and D were not observed. The ASTM ferritic *austenite* grain size number in the longitudinal direction and in the transverse direction is 7.2 according to ASTM E112. Figure 3 presents the observed inclusions of AISI AISI 1050M Induction Surface Hardened steel. The inclusion area was measured using a JAVA image analysis system. The chemical composition of AISI 1050M Induction Surface Hardened steel was provided by SCI-Lab materials testing inc., 25 McIntyre place, unit 2, Kitchener, Ontario, N2R 1H1, and is shown in Table 1.

B) Strain-Life Data

The fatigue test data for AISI 1050M Induction Surface Hardened steel obtained in this investigation are given in table 2. The stress amplitude corresponding to each strain-amplitude was calculated from the peak load amplitude at one half the expected specimen life.

A fatigue strain-life curve for the AISI 1050M Induction Surface Hardened steel is shown in Figure 4, and may is described by the following equation:

$$\frac{\Delta\varepsilon}{2} = \frac{\sigma'_f}{E}(2N_f)^b + \varepsilon'_f(2N_f)^c$$

where
$\dfrac{\Delta\varepsilon}{2}$ = True total strain amplitude

$2N_f$ = Number of reversals to failure

σ'_f = Fatigue strength coefficient

b = Fatigue strength exponent

ε'_f = Fatigue ductility coefficient

c = Fatigue ductility exponent

Where σ'_f =3251.5 MPa, b = -0.0970, ε'_f = 0.8102 and c = -0.8720. These values of the strain-life parameters were determined from fatigue testing over the range: $0.002 < \dfrac{\Delta\varepsilon}{2} < 0.01$.

C) Cyclic Stress-Strain Curves

Stabilized and half life stress data obtained from strain-life fatigue tests were used to obtain the companion cyclic stress-strain curve shown in figure 5. The true cyclic stress-strain curve is described by the following equation:

$$\varepsilon = \frac{\sigma}{E} + \left(\frac{\sigma}{K'}\right)^{\frac{1}{n'}}$$

where ε = True total strain amplitude

σ = Cyclically stable true stress amplitude

K' = Cyclic strength coefficient

n' = Cyclic strain hardening exponent

Where $K' = 3539.40$ MPa and $n' = 0.1167$.

D) Mechanical Properties

The engineering monotonic stress-strain curve is given in figure 6. The monotonic and cyclic properties are included in Appendix 1. The Hardness of the AISI 1050M Induction Surface Hardened steel taken as the average of three randomly chosen fatigue specimens and is given in Appendix 1. The individual hardness measurements are also given in Table 2. The true monotonic and true cyclic stress-strain curves plotted together are given in figure 7.

REFERENCES

[1] Pompetzki, M.A., Saper, R.A., and Topper, T.H., "Software for High Frequency Control of Variable Amplitude Fatigue Tests," Canadian Metallurgical Quarterly, Vol. 25, No. 2, pp. 181-194, 198.

[2] J. A. Bannantine, J. J. Comer, and J. L. Handrock (1990), In :Fundamentals of Metal Fatigue Analysis, Prentice Hall, London.
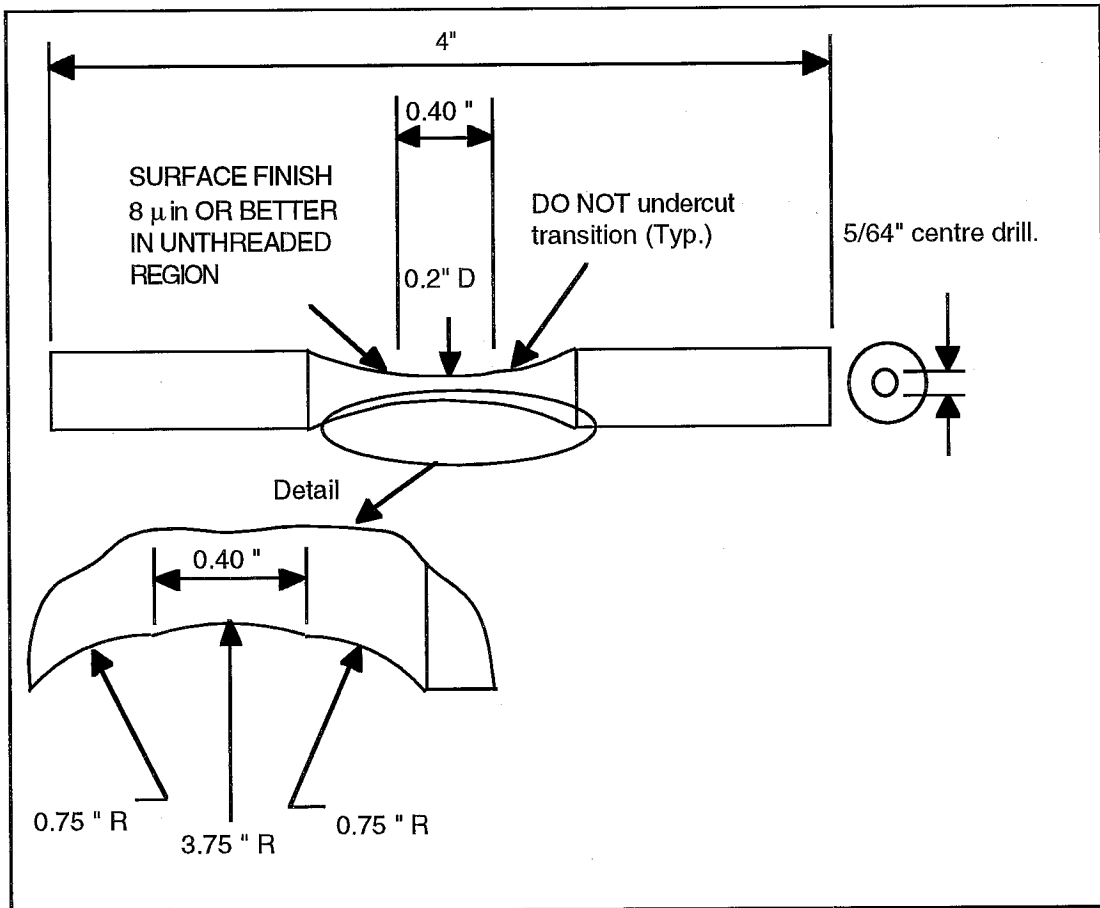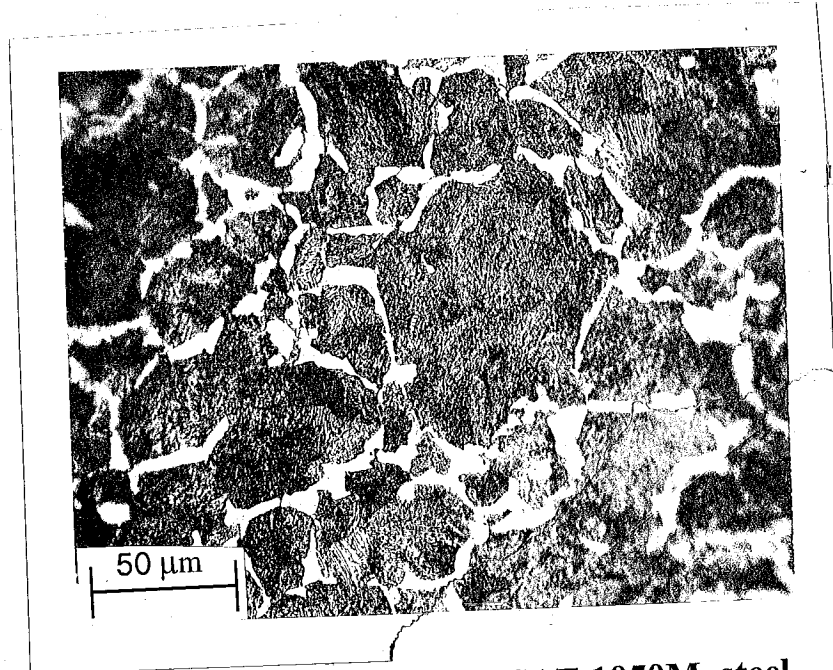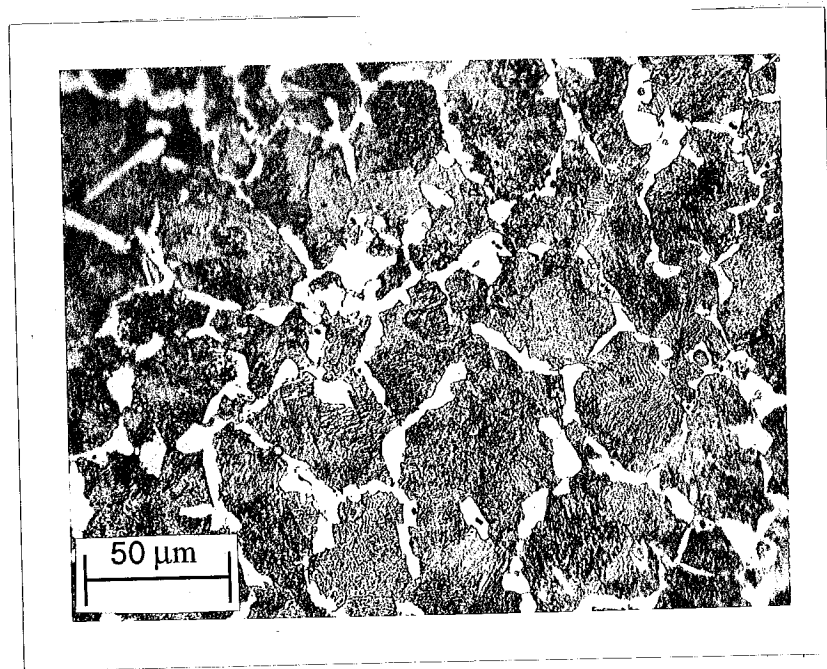
Fig. 1 Smooth cylindrical fatigue specimen

ITER 5: Photomicrograph of SAE 1050M steel, Hot Rolled, and Cold Extruded to Rb-98. 500X Mag.

(b) Transverse direction

Fig. 2 Photomicrograohs of AISI 1050M Induction Surface Hardened steel (X500):
(a) Longitudinal direction, and (b) Transverse direction.

Fig. 3 Inclusions photomicrograoh of AISI 1050M Induction Surface Hardened steel (X200)
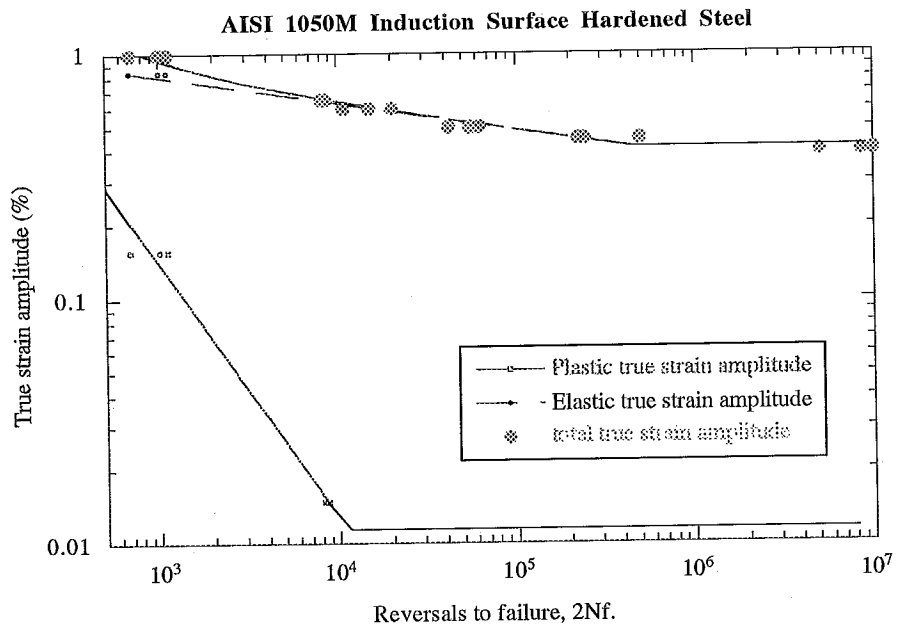
AISI 1050M Induction Surface Hardened Steel

Fig. 4 Constant amplitude fully reversed strain-life curve
for AISI 1050M Induction Surface Hardened steel.

AISI 1050M Induction Surface Hardened Steel

Fig. 5 Monotonic stress-strain curve for AISI 1050M Induction Surface Hardened steel

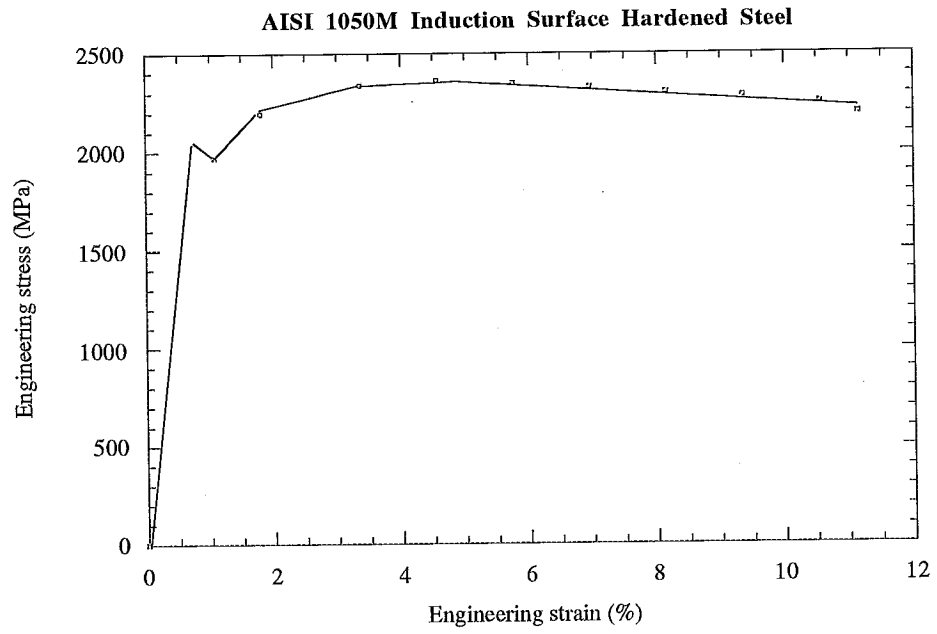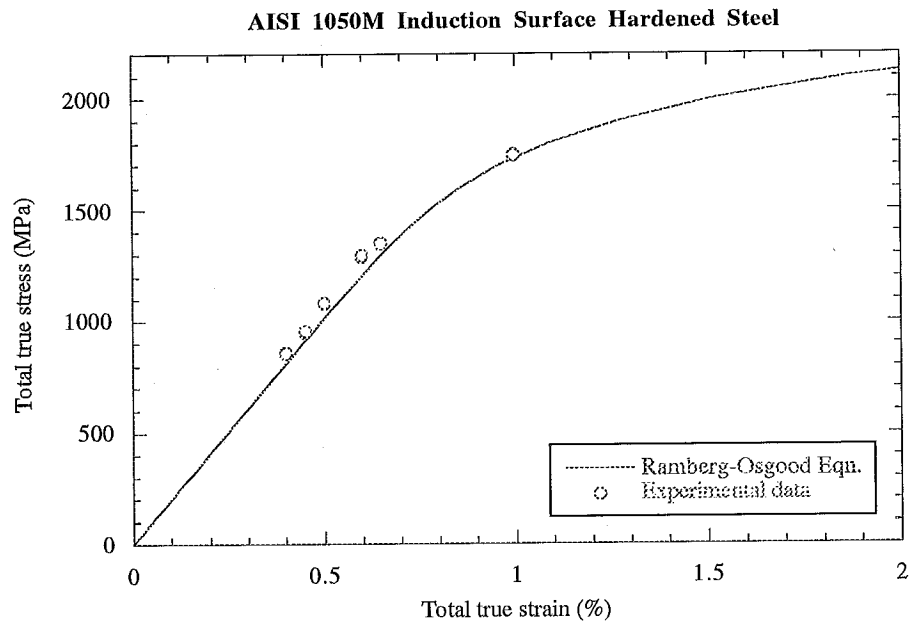**AISI 1050M Induction Surface Hardened Steel**

Fig. 6 Cyclic stress-strain curve for AISI 1050M Induction Surface Hardened steel
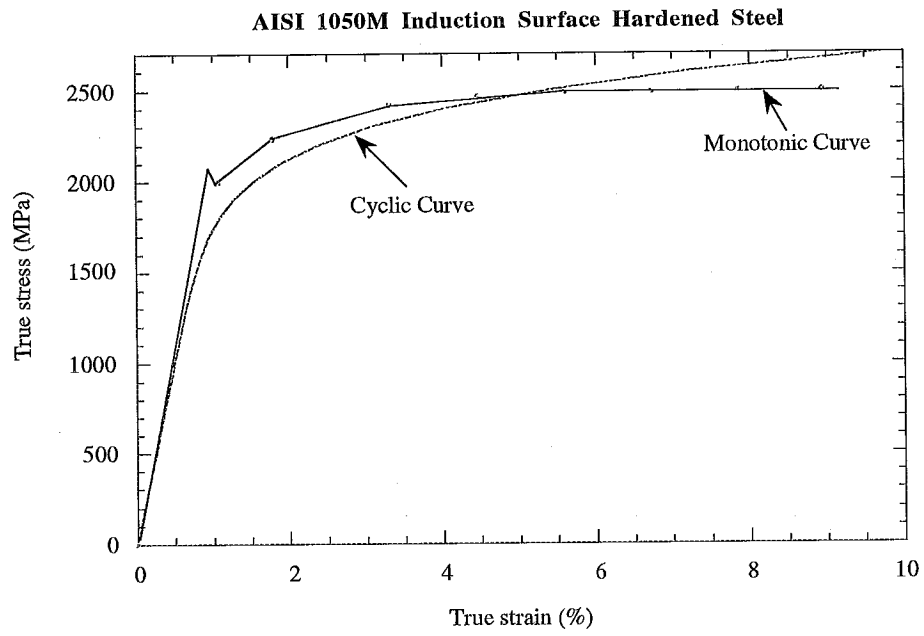
Fig. 7 Monotonic and Cyclic stress-strain curves for AISI 1050M Induction Surface
Hardened steel

Table 1 Chemical composition of AISI 1050M Induction Surface Hardened steel

Carbon, C	0.52%
Manganese, Mn	0.86%
Phosphorous, P	0.021%
Sulfur, S	0.024%
Silicon, Si	0.27%
Copper, Cu	0.01%
Nickel, Ni	<0.01%
Chromium, Cr	0.05%
Molybdenum, Mo	<0.01%
Vanadium, Va	0.003%
Calcium, Ca	0.006%
Boron, Bo	0.0024%
Aluminum, Al	0.039%
Titanium, Ti	0.001%
Oxygen, O	0.0014%
Columbium, Cb	0.003%

Appendix 1

Monotonic Properties for AISI 1050M Induction Surface Hardened steel

Average Elastic Modulus, E	=	219.50 GPa
Upper Yield Strength	=	2050 MPa
Lower Yield Strength	=	1090 MPa
Monotonic Yield Strength, (0.2% offset)	=	2100 MPa
Ultimate tensile Strength	=	2360 MPa
% Elongation	=	16.66 %
% Reduction of Area	=	14.67 %
True fracture strain, $Ln\ (A_i/A_f)$	=	16 %

True fracture stress, $\sigma_f = \dfrac{P_f}{A_f}$ = 2572.76 MPa

Bridgman correction, $\sigma_f = \dfrac{P_f}{A_f} \Big/ \left(1+\dfrac{4R}{D_f}\right) Ln\left(1+\dfrac{D_f}{4R}\right)$ = 2115 MPa

Monotonic strength coefficient, K	=	3045 MPa
Monotonic strain hardening exponent, n	=	0.0716
Hardness, Rockwell C (HRC)	=	54 HRC
Hardness, Brinell	=	536

Cyclic Properties for AISI 1050M Induction Surface Hardened steel

Cyclic Yield Strength, (0.2% offset) $= K'(0.002)^{n'}$	=	1714 MPa
Cyclic strength coefficient, K'	=	3539.40 MPa
Cyclic strain hardening exponent, n'	=	0.1167
Fatigue Strength Coefficient, σ'_f	=	3251.50 MPa
Fatigue Strength Exponent, b	=	-0.097
Fatigue Ductility Coefficient, ε'_f	=	0.8102
Fatigue Ductility Exponent, c	=	-0.8720

P_f:	Load at fracture.
A_i and A_f:	Specimen cross-section area before and after fracture.
R:	Specimen neck radius.
D_f	Specimen diameter at fracture.

Table 2 Tensile and Fatigue Test Data for 1050M Induction Surface Hardened steel

Sp#	TRUE Total Strain Amplitude(%)	TRUE Stress Amplitude (MPa)	TRUE Plastic Strain Amplitude(%)	TRUE Elastic Strain Amplitude(%)	(50% load drop) Fatigue Life (Reversals, 2Nf)	MONOTONIC Young's Modulus(GPa)	Hardness (HRC)
22	0.995	1744.7	0.212	0.783	1000.0	220	54
12	0.995	1722.6	0.222	0.774	1108.0	219.5	
9	0.995	1744.7	0.212	0.783	688.00	220.5	
15	0.647	1349.9	0.038	0.609	8194.0	219	
14	0.647	1365.3	0.032	0.616	8628.0	219	55
7	0.647	1387.4	0.022	0.626	8362.0	219	
28	0.598	1296.2	0.013	0.585	10892	219.5	
1	0.598	1287.4	0.017	0.581	15054	219.5	
16	0.598	1260.9	0.029	0.569	20319	219.5	54.5
26	0.498	1061.1	0.019	0.479	42172	219	
11	0.498	1065.5	0.017	0.481	63562	219	
17	0.498	1100.8	0.000	0.497	55646	219	
13	0.448	952.51	0.017	0.431	2.4606e+05	219.5	54
4	0.448	954.71	0.016	0.432	5.0000e+05	220	
2	0.448	1104.6	0.000	0.499	2.2718e+05	220	
6	0.399	857.27	0.011	0.388	8.6078e+06	220	53.5
20	0.399	859.47	0.009	0.389	5.0528e+06	220	
12	0.399	835.23	0.021	0.378	1.0000e+07*	219	54

* Run out

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