Further Report on Repeated Impact Tests.

By

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1. Depth of Notch and Blow Number.

In the author's previous report[1] on the repeated impact tests the steel containing 0.25% carbon showed the maximum resistance and it was remarked that this maximum will probably take place for a different carbon content, if the form and the depth of notch be altered. Further tests were made with the remaining pieces of the same flat bars used in the previous tests, altering the depth of notch.

From each bar (Steel grades No. 1 to No. 6) were cut 24 test pieces A_1 to A_8, B_1 to B_8 and C_1 to C_8 as shown in Fig. 1.

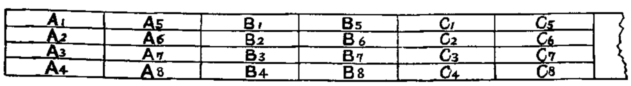
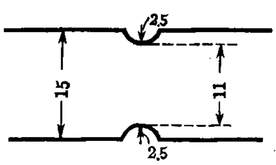


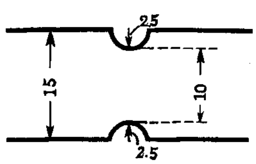
Fig. 1.

The depth of notch was made 2 mm. in the pieces A_1 to A_8, 2.5 mm. in the pieces B_1 to B_8 and 3 mm. in the pieces C_1 to C_8, its form all being circular of 2.5 mm. radius, as shown in Figs. 2 to 4.



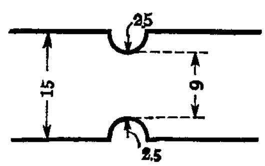
A_1 *to* A_8

Fig. 2.



B_1 *to* B_8

Fig. 3.



C_1 *to* C_8

Fig. 4.

1) This Memoirs, Vol. II. No. 2.

The blow numbers got in the author's repeated impact machine are recorded in Tables I to VI. The impact energy of single blow was taken at the rate of 30 cmkg. for 10 mm. thickness as before.

Table I.

Steel grade No. I; Thickness 11.6 mm.; Impact energy 34.8 cmkg.

Test piece	Blow number	Test piece	Blow number	Test piece	Blow number
A 1	638	B 1	421	C 1	357
A 2	798	B 2	446	C 2	309
A 3	640	B 3	438	C 3	363
A 4	603	B 4	432	C 4	367
A 5	701	B 5	456	C 5	346
A 6	632	B 6	475	C 6	403
A 7	708	B 7	440	C 7	325
A 8	638	B 8	468	C 8	337
mean	670	mean	447	mean	351

Table II.

Steel grade No. 2; Thickness 11.2 mm.; Impact energy 33.6 cmkg.

Test piece	Blow number	Test piece	Blow number	Test piece	Blow number
A 1	827	B 1	490	C 1	378
A 2	729	B 2	456	C 2	351
A 3	609	B 3	479	C 3	338
A 4	794	B 4	491	C 4	397
A 5	804	B 5	541	C 5	358
A 6	844	B 6	435	C 6	357
A 7	796	B 7	506	C 7	357
A 8	793	B 8	431	C 8	335
mean	775	mean	479	mean	359

Table III.

Steel grade No. 3; Thickness 11.1 mm.; Impact energy 33.3 cmkg.

Test piece	Blow number	Test piece	Blow number	Test piece	Blow number
A 1	777	B 1	519	C 1	351
A 2	769	B 2	497	C 2	359
A 3	877	B 3	503	C 3	391
A 4	769	B 4	434	C 4	399
A 5	979	B 5	525	C 5	373
A 6	856	B 6	509	C 6	385
A 7	868	B 7	623	C 7	397
A 8	825	B 8	515	C 8	419
mean	840	mean	516	mean	384

Table IV.

Steel grade No. 4; Thickness 11.3 mm.; Impact energy 33.9 cmkg.

Test piece	Blow number	Test piece	Blow number	Test piece	Blow number
A 1	653	B 1	281	C 1	282
A 2	765	B 2	430	C 2	306
A 3	632	B 3	405	C 3	271
A 4	630	B 4	432	C 4	324
A 5	593	B 5	451	C 5	297
A 6	619	B 6	425	C 6	320
A 7	590	B 7	352	C 7	323
A 8	522	B 8	442	C 8	318
mean	626	mean	402	mean	305

Table V.

Steel grade No. 5; Thickness 11.5 mm.; Impact energy 34.5 cmkg.

Test piece	Blow number	Test piece	Blow number	Test piece	Blow number
A 1	820	B 1	475	C 1	319
A 2	761	B 2	559	C 2	318
A 3	895	B 3	475	C 3	331
A 4	851	B 4	566	C 4	290
A 5	832	B 5	528	C 5	315
A 6	744	B 6	453	C 6	346
A 7	832	B 7	475	C 7	311
A 8	782	B 8	490	C 8	301
mean	815	mean	503	mean	216

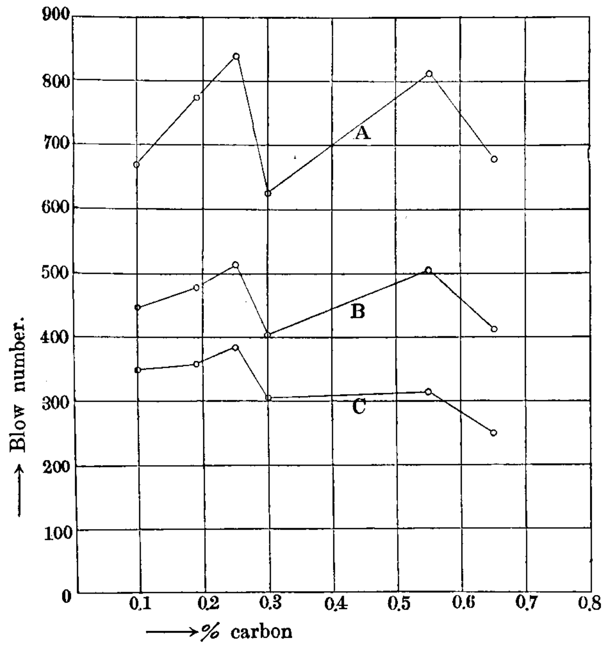
Table VI.

Steel grade No. 6; Thickness 11.45 mm.; Impact energy 34.35 cmkg.

Test piece	Blow number	Test piece	Blow number	Test piece	Blow number
A 1	717	B 1	370	C 1	279
A 2	631	B 2	270	C 2	243
A 3	756	B 3	280	C 3	201
A 4	815	B 4	279	C 4	203
A 5	729	B 5	460	C 5	263
A 6	548	B 6	487	C 6	232
A 7	596	B 7	477	C 7	300
A 8	638	B 8	655	C 8	268
mean	679	mean	410	mean	249

The mean blow numbers are plotted in Fig. 5, taking percentages of carbon as abscissae.

Fig. 5.



From Fig. 5 we observe that:

1. The steel grade No. 3 has the maximum resistance in all cases.

2. Increasing the depth of notch the diagram is flattened, the peak of the maximum becomes lower and the blow number falls at a greater rate as a steel contains more carbon.

The consequence of the item 2 must be the tendency of shifting the the maximum point towards the left, but it is very small as not apparent in Fig. 5, so that the influence of depth of notch on the position of the maximum point may be disregarded.

One thing that will not escape from our notice in the present three series of test as well as the series in the former report is that, the steel grade No. 4 has comparatively a very low resistance. This caused the author to suspect some defects in its structure and naturally led him to microscopical observations.

The test pieces whose blow number is near to the mean blow number were selected and observed under microscope. Figs. 6 to 11 show the structure of the pieces 1C5, 2C6, 3C3, 4C5, 5C1 and 6C2 at the section *a b*, Fig. 12, near the fracture.

The piece 4C5 shows a somewhat irregular distribution of pearlite particles, while the tendency of the piece 3C3 to the Widmanstättian structure, characteristic to steel in cast condition or that subject to a deficient forging or rolling, is striking.

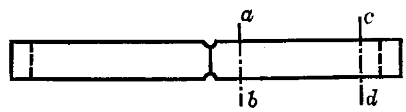


Fig. 12.

Figs. 13 to 16 show the structure of the pieces 3C5, 3C6, 4C2 and 4C8 at the section *a b* near the fracture and Figs. 17 to 20 that of the same pieces at the section *cd* near the end.

Comparing the photographs of the grades No. 3 and No. 4, if a defective structure have influences upon the resistance to repeated impacts, the grade No. 3 would, to the contrary to the fact, have shown a lower resistance than No. 4. We had, therefore, to look for the other causes.

A further trial made was the determination of sulphur and phosphorus contents. Table VII shows the results of analysis.

Table VII.

Test piece	1 C 5	2 C 6	3 C 3	4 C 5	5 C 1	6 C 2
Blow number	346	357	391	297	319	243
C %	0.102	0.19	0.25	0.30	0.55	0.65
P ,,	0.025	0.040	0.067	0.075	0.045	0.048
S ,,	0.034	0.059	0.024	0.039	0.061	0.041

The grade No. 4 contains 0.075% phosphorus, while that No. 3 only 0.067%. The other grades contain much less percentage of phosphorus.

Comparing the grades No. 3 and No. 4 we may assume for the present that a more phosphorus content in conjunction with a greater percentage of carbon is at least a cause of weakness of the grade No. 4.

2. Phosphorus Content and Blow Number.

In the foregoing test a rough idea on the relation between the phosphorus content and the resistance to repeated impacts was obtained. With a view to further research on the relation the comparative tests on steel bars of possibly uniform composition, but with different amounts of phosphorus were intended. The Osaka Arsenal was kind enough to undertake the manufacture and supply of the bars. They are 7 in kinds and all $\frac{3}{4}$ in. in diameter. The result of analysis by the arsenal is reproduced in Table VIII.

Table VIII.

No.	C	Si	P	S	Mn	Cu
2	0.322	0.123	0.019	0.017	0.825	0.14
3	0.331	0.222	0.028	0.014	0.614	—
4	0.276	0.231	0.037	0.016	—	—
5	0.312	0.242	0.048	0.014	0.507	0.10
6	0.267	0.244	0.065	0.014	0.482	0.10
7	0.324	0.291	0.078	0.014	0.457	0.13
8	0.268	0.272	0.088	0.016	0.490	0.13

From each bar three test pieces for tension and eight for repeated impact were taken, the latter being of the form as shown in Fig. 21. The result of tension tests is recorded in Table IX and that of repeated impact tests in Table X. They are shown graphically in Fig. 22.

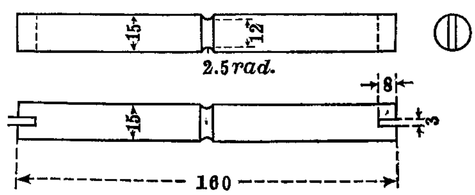


Fig. 21.

Table IX.

Test piece 13 mm. dia × 50 mm. gauge length.

Bar No.	No. of tests from which the mean is taken	Strength kg/cm²	Elongation %	Area contraction %	Yielding stress kg/cm²
3	2	5482	30.6	55.0	3390
4	2	4946	35.8	65.8	3459
5	3	5609	32.0	61.1	3702
6	3	5483	34.1	59.7	3676
7	3	5863	31.5	56.7	3814
8	3	5961	30.3	51.1	3595

Table X.

Blow numbers.

Bar No.	Phosphorus %	Test piece A	B	C	D	E	F	G	H	K	Mean
2	0.019	746	960	1041	871	960	898	833	1180	893	931
3	0.028	1011	974	843	1149	1471	1233	944	1235	797	1073
4	0.037	1058	897	1101	1156	1179	1105	1022	1005	974	1055
5	0.048	1116	1055	1160	929	1223	879	1175	1031	853	1046
6	0.065	1107	889	1037	1183	1136	1267	1235	1252	1251	1150
7	0.078	740	776	689	786	935	669	1084	878	700	806
8	0.088	905	820	999	921	595	717	782	947	1027	857

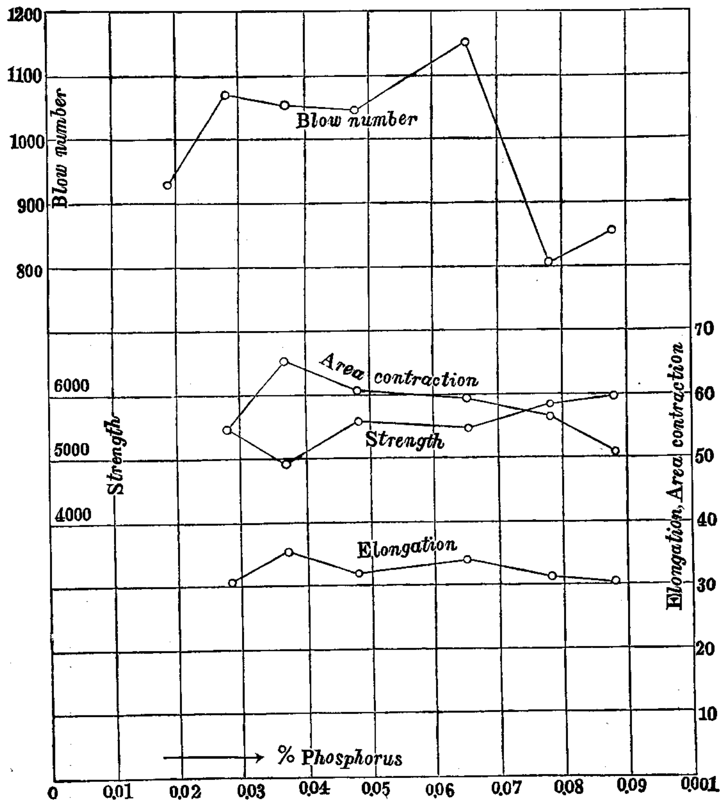


Fig. 22.

From Fig. 22 it may be assumed that in the mild steel containing about 0.3% carbon the effect of phosphorus on the resistance to repeated impacts is not appreciable, so far as its contents is less than about 0.07% and first when this limit it exceeded, the resistance is spoiled.

3. Blow Number and Upton-Lewis' Toughness Number.

A comparison of result of the author's test with that of Upton-Lewis toughness test was tried. As the test materials basic steel round bars 1⅜ ins. diameter × 1 m. length were supplied by the Imperial Steel Works of Yawata. To the steel bars a list of analysis made in the Steel Works was annexed, which will be reproduced in Table XI.

Table XI.

Bar No.	Number of melt	Analysis				
		C	Mn	Si	P	S
1	89975	0.10	0.36	—	0.022	0.037
2	90289	0.15	0.37	—	0.038	0.032
3	91144	0.20	0.45	—	0.023	0 038
4	90907	0.29	0.56	1.78	0.018	0.041
5	73892	0.35	0.78	1.88	0.034	0.019
6	90141	0.40	0.71	1.50	0.044	0.023
7	90577	0.46	0.80	1.87	0.032	0.036
8	89608	0.50	0.75	1.68	0.024	0.041
9	89635	0.55	0.69	1.60	0.024	0.031
10	90749	0.59	0.54	2.44	0.024	0.046
11	84467	0.65	0.67	2.37	0.043	0.029
12	91061	0.71	0.59	2.46	0.015	0.035

Each bar was cut into two lengths and forged flat under a steam hammer in the college workshop, one to about 15 mm. thickness for the repeated impact pieces and the other to about 12 mm. for the Upton-

Lewis' pieces. Atmost care was taken to forge all bars under equal conditions, that is to forge in one heating from the due initial temperature, keeping blow powers of hammer alike and to cool in the atmosphere in a similar manner.

From each bar six repeated pieces and four Upton-Lewis' pieces were obtained as in Fig. 23.

Fig. 23.

The Upton-Lewis' machine was adjusted to the crank radius of $\frac{3}{4}$ in. Each test piece was tested three times, that is broken in three sections and the intermediate repetition number was taken.

Tables XII and XIII give the results of the author's and the Upton-Lewis' tests respectively. Plotting as usual the mean values in these tables in dependence on carbon content and drawing curves we get Fig. 24.

Table XII.

Blow numbers.

Test piece rectangular and 10 mm. in thickness; Impact energy 30 cmkg.

Bar No.	Carbon %	Mark						Mean
		A	B	C	D	E	F	
1	0.10	303	350	362	298	412	337	344
2	0.15	367	362	322	422	328	345	358
3	0.20	298	319	323	292	278	294	301
4	0.29	365	281	355	355	279	304	323
5	0.35	440	451	416	447	465	431	442
6	0.40	366	368	377	399	475	421	401
7	0.46	376	419	405	355	534	424	419
8	0.50	281	288	274	287	309	295	289
9	0.55	307	310	278	293	265	231	281
10	0.59	143	102	112	142	119	114	122
11	0.65	66	157	119	132	138	72	114
12	0.71	108	116	122	144	113	133	123

Table XIII.

Test piece 1 in. in width × $\frac{1}{4}$ in. in thickness.

n = number of repeated bendings and M = mean moment resisted by the test piece in in-lbs.

Bar No.	Carbon %	G		H		K		L		Mean nM (rounded)
		n	M	n	M	n	M	n	M	
1	0.10	1470	303	1305	305	1380	303	1375	321	426000
2	0.15	1353	284	1485	300	1275	309	1380	309	413000
3	0.20	930	384	1190	302	1405	378	1245	313	409000
4	0.29	1316	345	930	384	705	360	1216	321	364000
5	0.35	1408	454	1380	429	1068	409	990	444	527000
6	0.40	1131	411	1366	415	973	399	1040	409	461000
7	0.46	1605	390	1535	399	1005	376	1192	374	516000
8	0.50	985	460	820	384	1290	366	1060	437	426000
9	0.55	1200	450	850	460	970	370	1400	387	458000
10	0.59	1135	456	1120	439	1063	450	744	444	454000
11	0.65	744	507	593	501	554	431	770	443	314000
12	0.71	945	380	940	419	933	411	905	456	387000

In the Upton-Lewis' test some of the test pieces endured, before breaking asunder, a tolerably great number of repeated bendings, without imparting any compression to the load indicating springs. In counting the number of repetition n such bendings were excluded.

As seen from Fig. 24 both the blow number as well as the Upton-Lewis' toughness number nM show similarly the maximum value for about the same carbon content, but the blow number falls at a faster rate than nM as the amount of carbon increases.

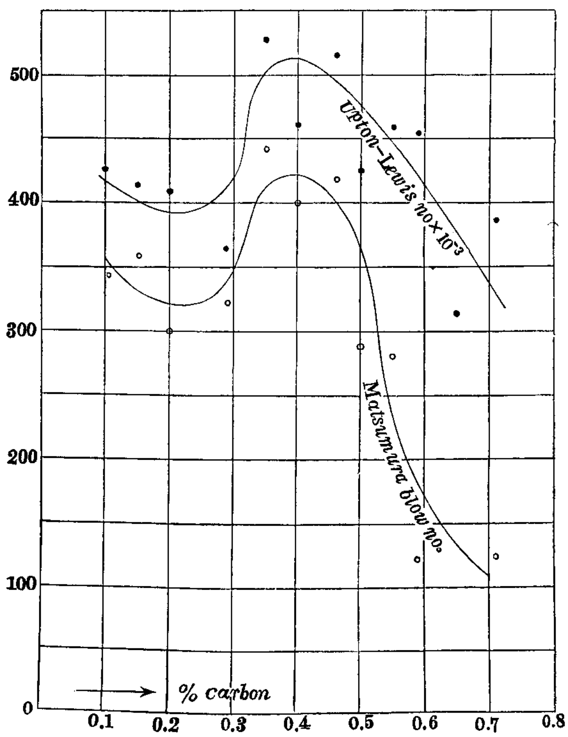


Fig. 24.

Comparing the result of the present repeated impact test with that of the previous test the percentage of carbon, for which the maximum resistance takes place, is not exactly alike. It was previously 0.25%, while is here 0.35 to 0.45%. The discordance is probably due to the influence of impurities other than carbon, especially of phosphorus.

The occurrance of the maximum resistance is also observed when test is made

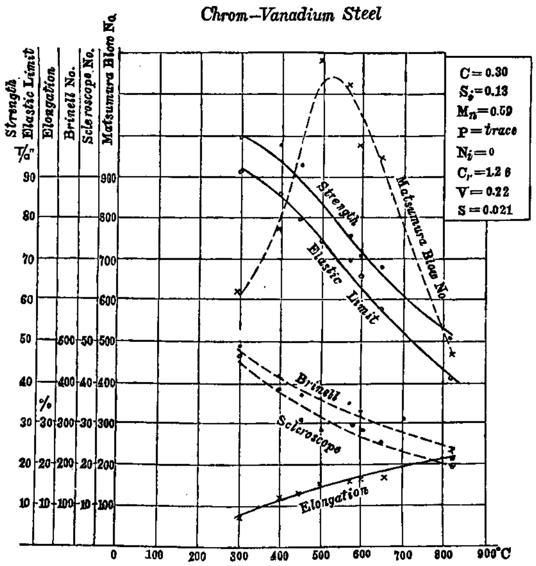


Fig. 25.

with special steels quenched from above A_3 point and annealed at different temperatures. Some of the results of repeated impact and other tests[1] made by Commander Yamashita of Yokosuka may be quoted here. Figs. 25 and 26 show the relation between annealing temperature and mechanical properties.

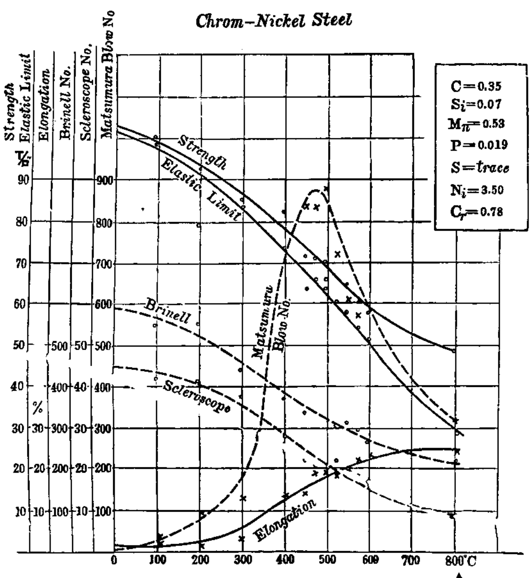


Fig. 26.

Figs. 24 to 26 show that the resistance to repeated impacts varies very considerably in dependence

1) J. Soc. Mech. Eng. Tokyo, Vol. XXIV, No. 65.

on carbon content in ordinary steel and in dependence on thermal treatment in special steel. This accounts for the importance of repeated impact test for the material used as a construction part more or less subject to shock.

4. Impact Energy and Blow Number.

From a mild steel steel round bar of $\frac{3}{4}$ in. in diameter got from market, 18 round test pieces, as shown in Fig. 21, were taken and tested in the repeated impact machine, each under a different impact energy. The result is recorded in Table XIV and are shown by points in Fig. 27.

Table XIV.

Impact energy cmkg.	Blow number	Impact energy cmkg.	Blow number	Impact energy cmkg.	Blow number
20	2063	28	1248	40	665
21	1950	30	1016	42	670
22	2208	32	1039	44	571
23	1600	34	1026	46	519
24	1513	36	872	48	563
26	1431	38	669	50	436

To result may be formulized to

$$n=\frac{30800}{e^{1.65}}$$

where n represents the blow number and e the impact energy in cmkg. The curve in Fig. 27 was drawn according to this formula.

Summary.

1. The remaining pieces of the same flat bars in the previous repeated impact test were utilized for furthur tests to find the effect of depth of notch on the result and it is ascertained that increasing depth of notch the blow number falls at a greater rate as a steel contains more carbon. As the consequence the maximum resistance must take

place for a smaller carbon content but the influence is very small and may be disregarded.

2. The comparative tests on steel bars of possibly uniform composition but with different amount of phosphorus were performed and it is found that in the mild steel containing about 0.3% carbon the effect of phosphorus on the resistance to repeated impacts is not appreciable, so far as its content is less than about 0.07% and first when this limit is exceeded, the resistance is spoiled.

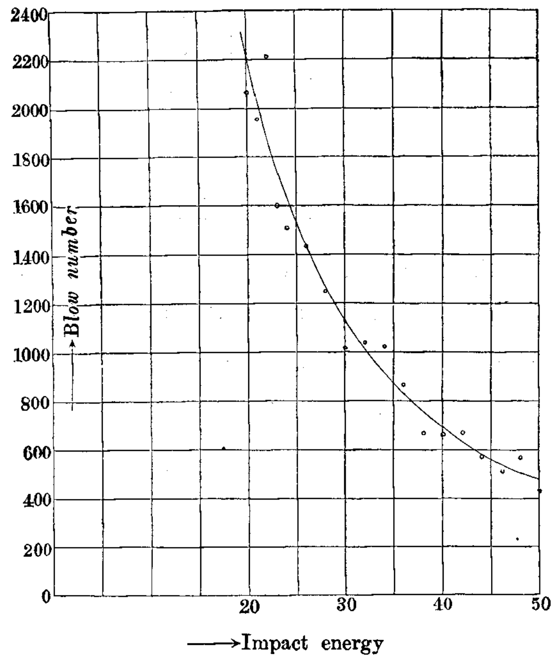


Fig. 27.

3. A comparison of the blow number with the Upton-Lewis' toughness number nM for the steel grades containing from 0.1 to 0.71% of carbon was made. Both the blow number as well as the toughness number nM show similarly the maximum value for about the same carbon content, but the blow number falls at a faster rate than nM as the amount of carbon increases.

4. Test pieces cut from a mild steel bar were tested in the repeated impact machine, each under a different impact energy and the result is formulized to.

$$n=\frac{30800}{e^{1.65}}$$

n being the blow number and e the impact energy in cmkg.

In conclusion the author expresses his hearty thanks to the Imperial Steel Works and the Osaka Arsenal for supplying the test materials and to Mr. Tsunejiro Nakai for the zealous assistance throughout the work.

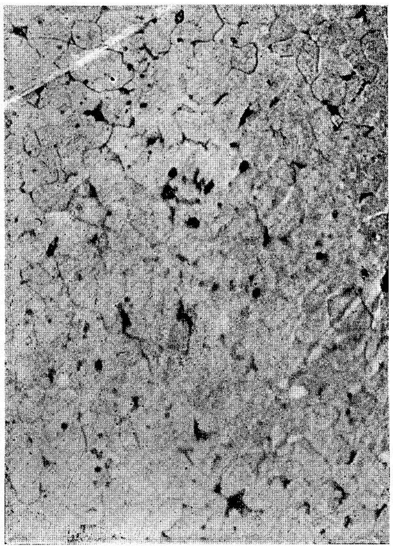


Fig. 6.
Test piece 1C5. Blow no. 346.
200 dias.

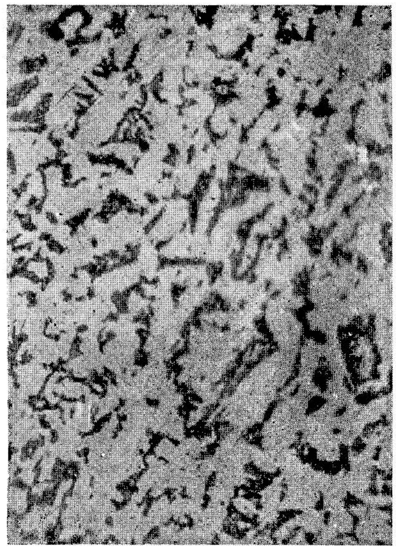


Fig. 7.
Test piece 2C6. Blow no. 357.
200 dias.

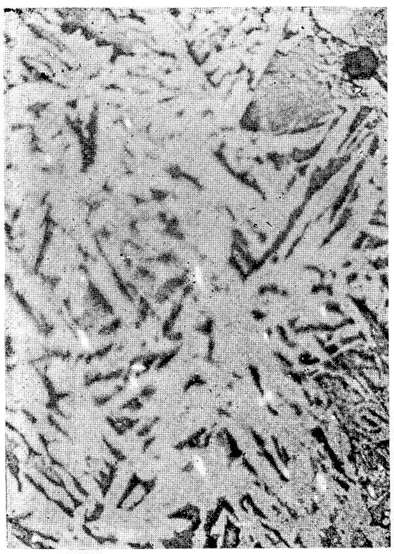


Fig. 8.
Test piece 3C3. Blow no. 391.
200 dias.

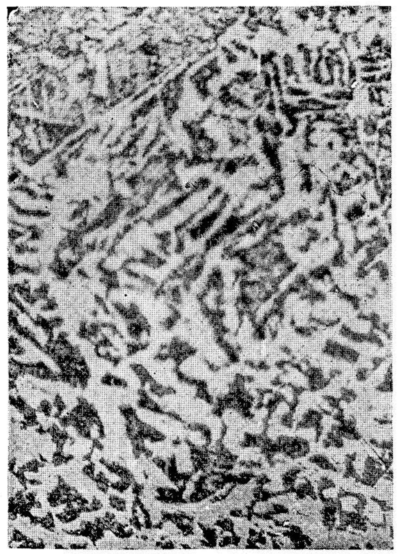


Fig. 9.
Test piece 4C5. Blow no. 297.
200 dias.

Fig. 10.
Test piece 5C1. Blow no. 319.
200 dias.

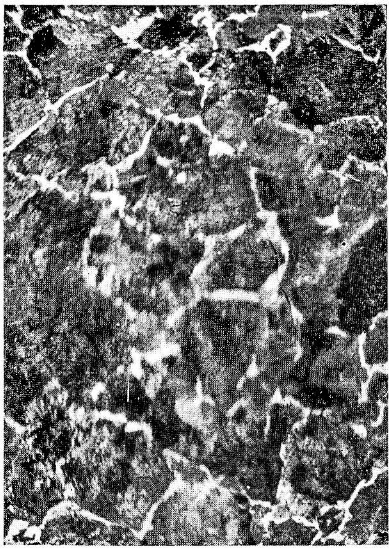


Fig. 11.
Test piece 6C2. Blow no. 243.
200 dias.

Fig. 13.
Test piece 3C5. Blow no. 373.
200 dias.

Fig. 14.
Test piece 3C6. Blow no. 385.
200 dias.

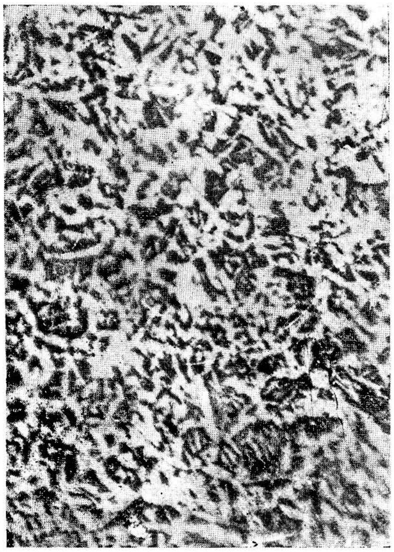


Fig. 15.
Test piece 4C2. Blow no. 306.
200 dias.

Fig. 16.
Test piece 4C8. Blow no. 318.
200 dias.

Fig. 17.
Test piece 3C5. Blow no. 373.
200 dias.

Fig. 18.
Test piece 3C6. Blow no. 385.
200 dias.

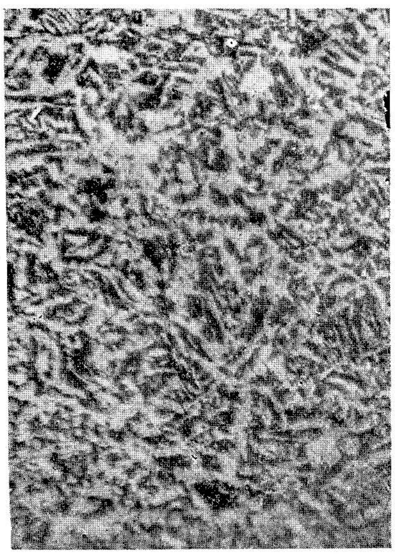


Fig. 19.
Test piece 4C2. Blow no. 306.
200 dias.

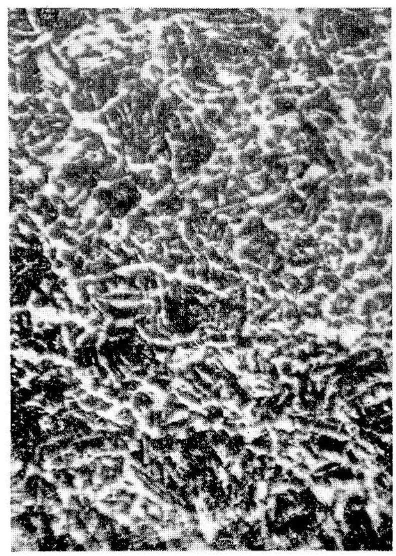


Fig. 20.
Test piece 4C8. Blow no. 318.
200 dias.