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LX. *Recovery of Nickel and Carbon Steel from Overstrain.*
 By E. L. HANCOCK, *Assistant Professor of Applied Mechanics, Purdue University* *.

[Plate XVI.]

IT has been known for some time that wrought iron when stressed to its ultimate strength, but not fractured, will, when allowed to rest, show a higher ultimate strength and a higher limit of elasticity. This fact was discovered, independently, by Captain Beardslee and by Professor Thurston. Later experimenters on the subject of overstrain of iron and steel have confined their attention, for the most part, to the behaviour of these materials after they have been stressed to the yield-point. This yield-point is the elastic limit of the contractor, and is often so designated. The true elastic limit, however, or proportional limit has a value somewhat less than the yield-point.

Yield-Point Phenomena.

The yield-point might be defined as that load at which the piece elongates considerably, forming a flat place in the stress-strain diagram. The material under this load seems to be in a somewhat plastic condition, similar to that shown by ductile materials when they have been stressed to the ultimate strength, and rapid deformation takes place. The yield-point has always been a subject of interest to those interested in the elasticity of materials. The great deformation at this point without any increase of load indicates a peculiarity in the molecular condition or arrangement caused by the stress. The desire to know the effect of loads great enough to stress iron or steel to this yield-point, and the recovery of these materials after release from such loads, brought about the investigations reported in this paper.

Previous Investigations.

It has been known for some time that iron or steel stressed to the yield-point in tension or compression exhibits no elasticity when subjected to stress of the opposite kind. That is, a piece overstrained in tension shows no elasticity in compression and *vice versa*. (In this paper a piece is considered overstrained when the stress has reached the yield-point and the deformation has been allowed to take place.)

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 Communicated by the Author.

The question naturally arose in this connexion as to whether or not the elasticity returned, and if so, what were the most favourable conditions for early recovery. The most important investigation of the subject, carried on in Europe, is reported by Mr. J. Muir, in the Philosophical Transactions of the Royal Society of London, vol. A, 1900. The report deals with the recovery from overstrain in tension only, and includes the following :—

- (a) Recovery from overstrain—Specimens allowed to rest.
- (b) " " " Specimens kept under stress.
- (c) " " " Specimens kept at moderate temperature.
- (d) " " " Specimens subjected to mechanical vibration.
- (e) " " " Specimens subjected to magnetic agitation.

The conclusions reached as a result of these investigations are :—

- (a) Elastic properties gradually restored (see Pl. XVI. fig. 1).
- (b) Only a few tests made, but evidence seems to show that that treatment produces little effect.
- (c) Recovery accelerated to a considerable extent.
- (d) Recovery hindered.
- (e) No appreciable effect upon recovery.

The diagrams resulting from the tests of one of the specimens of the series (a), as reported by Muir, in the article referred to above, are shown in fig. 1 (Pl. XVI.). The material used for this test was steel, one inch solid round, having an ultimate strength of 64,000, a yield-point of 54,000, and a percentage of elongation in 8 inches of 23. As indicated in the drawing (see fig. 1), the specimen was first stressed to the yield-point (see curve 1). Ten minutes later test No. 2 was made; the corresponding curve shows that the overstrain in the first test entirely destroyed the elastic limit and the modulus of elasticity of the specimen. Tests 3, 4, and 5 were made after intervals of 4 hours, 23 hours, and 2 days 22 hours respectively. The corresponding curves show that the elasticity is gradually restored by rest. Test No. 6, made 6 days 3 hours after No. 1, shows the elasticity restored, the elastic limit being even a little higher than originally. This test was continued until a new yield-point of the material was reached, that is, it was again overstrained. This second overstrain again destroyed the elastic properties, as shown by test No. 7 made 20 minutes

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after No. 6 (see curve 7). The specimen was now allowed to rest 472 days, when it was again tested. This last test No. 8 shows the elasticity again restored, the elastic limit raised, and the modulus of elasticity the same as originally.

Tests made at Purdue University.

Some tension tests of nickel-steel similar to those outlined above, were made by Professor W. K. Hatt, and reported by him in the 'Proceedings' of the Indiana Academy of Science. The results obtained agree closely with those of Muir.

During the last three years further tests have been made in the Laboratory for Testing Materials of Purdue University, under the direction of Prof. E. J. Fermier and the writer. The work planned included an investigation of the recovery of structural carbon-steel and low nickel-steel from overstrain in both tension and torsion. Part of this work has been completed and the results are given in this paper. The work completed may be divided into three parts, viz. :—

- (1) Recovery from overstrain in tension.
- (2) " " " in direct torsion.
- (3) " " " in reverse torsion.

With the exception of the three and one half per cent. of nickel, the nickel-steel had the same chemical composition as the carbon-steel. The tension-test pieces were turned to a diameter of 0.75 inch for a length of 9 inches. The torsion specimens were 0.875 inch in diameter and about 20 inches long; they were left unturned, and were tested on a gauge length of 10 inches. Torsional deformations were measured with an Olsen troptometer.

Results of Tests.

Only a few typical curves are shown in this report. In fig. 2 is shown the results of tension tests on nickel-steel. The piece showed an elastic limit of 54,000 lbs. per sq. inch. The first test was continued until the piece was overstrained. Test No. 2, made 15 minutes later, shows that the elasticity was destroyed by the overstrain in No. 1. After a period of rest of 96 hours the piece was again tested. This test, No. 3, indicates a recovery of the elastic properties, the elastic limit now being 36,000 lbs. per sq. inch, and the modulus of elasticity being about the same as before the first test. Test No. 4, made 120 hours after No. 3, shows the elastic limit still higher, it now being 48,000. Test No. 5, made 792 hours after No. 4, shows the elasticity entirely restored. The

elastic limit—60,000—being somewhat higher than that shown by the first test. The slope of the curves 3, 4, and 5 shows that in the recovery from overstrain the piece regained the same modulus of elasticity as it had originally; this is indicated by the parallelism of the curves below the elastic limit. The curves show that overstrain destroyed the elastic properties of the piece and that these were restored by subsequent rest.

A summary of tension tests made on the carbon steel is shown in fig. 3. The test, No. 1, shows the elastic limit of the material to be 35,000 lbs. per sq. inch. This test was continued until the piece was overstrained. Test No. 2, made immediately after No. 1, shows that the elastic properties were entirely destroyed by the original overstrain. After a period of rest of 70 hours the piece was again tested, the curve, No. 3, shows a recovery of the elastic limit and modulus of elasticity. Tests 4 and 5, made after periods of rest, indicated in fig. 3, show a continued rise in the elastic limit, but no change in the modulus of elasticity. In test No. 5 the piece was again overstrained. Test No. 6, made immediately after this second overstrain, shows the elasticity again destroyed. The piece was now immersed in boiling water and subjected to its annealing effect for 15 min., when it was again tested. This treatment restored the elasticity of the material, shown by curve No. 7. The elastic limit, as shown by this last test, is higher than before, but the modulus of elasticity is the same.

Figure 4 shows the results of torsion tests on nickel-steel. The overstrain in the first test destroyed the elastic properties. This is shown by the second test made immediately. Tests 3, 4, and 5, made at intervals shown on the drawing, show a gradual recovery of the elastic limit and a return of the modulus of elasticity. Test No. 5 was continued until the piece was again overstrained. After 620 minutes the piece was again tested, but showed no elasticity. It was immersed in boiling-water 15 minutes and again tested (see curve No. 7), showing the elastic limit higher than before, and the modulus of elasticity restored.

The results of the direct torsion tests made on carbon-steel are shown in fig. 5. The original test shows an elastic limit of 28,000 inch-pounds moment. The test was continued until the piece was overstrained, as in the preceding case, and immediately retested showing an absence of elasticity. Tests 3, 4, 5, and 6 were made after different periods of rest. The elastic limit gradually returned and even exceeded the original amount by 1200 inch-pounds, and the modulus of elasticity

returned to its original value. The piece was again overstrained in test No. 6, destroying the elasticity. Immersion in boiling water restored the elasticity (see curve 8).

Figure 6 shows the results of tension tests made on carbon steel. The piece was first overstrained and then tested again immediately, showing no elasticity in this second test. It was desired to see what effect mechanical agitation of the piece would have on the recovery of its elastic properties. After subjecting it to 500 end blows of a twenty oz. hammer, the third test was made. This test, made 40 minutes after No. 2, shows little or no recovery due to the treatment.

The results of the reverse torsion tests are shown in figures 7 and 8. In the first test (curve marked direct) the piece was overstrained. The curve marked "reverse immediately" shows the result of an immediate torsion test in the opposite direction. The test shows the elasticity destroyed. After a period of rest of 7 days similar pieces were reversed. The curve in this case shows an elastic limit of 9000 lbs. per sq. inch at the outer fibre, and a modulus of elasticity the same as originally. Fig. 8 is self-explanatory and needs no comment.

The direct torsion may be regarded as a test that should bring out the same facts as those developed by the tension tests, since elements on a 45 degree helix were in simple tension. From this point of view the outer fibres may be considered overstrained in tension. A release of the load and subsequent treatment, similar to that given the tension specimens, should bring out the same facts. Similarly the tests in reverse torsion may be regarded as tests in which the material was first overstrained in tension and then tested in compression. This is seen to be the case when it is remembered that a helix under tension in the first test was under compression in the reverse test. Looking at the matter in this way, it is seen that the results of the reverse torsion tests are in exact agreement with facts previously known, viz., that when iron or steel is overstrained in either tension or compression it loses its elasticity for stress of the opposite kind.

General Conclusions.

It is seen from the curves exhibited :—(a) That an overstrain in either tension or torsion destroys the elasticity of the material, but that this elasticity gradually returns when the piece is allowed to rest, the elastic limit becoming, in some cases, greater than its original value, and the modulus of elasticity the same as its original value. (b) That the

elastic properties of the overstrained material are restored by immersion for a short time in boiling-water. (c) That recovery is not aided by repeated impact from a light hammer. (d) Materials overstrained in either tension or compression lose their elasticity for stress of the opposite kind, but the elasticity is restored by rest. (e) The carbon-steel seems to recover more quickly than the nickel-steel. This, however, has not been shown conclusively by these tests, but all evidence goes to show that it is true.

The writer wishes to acknowledge the efficient help of the following senior students who assisted in carrying out the testing work:—Mr. Henry Jacobson and Mr. Harry W. Steindorf, of the class of 1906; Mr. Clinton G. Reed, Mr. Lawson Stone, Mr. F. O. Blair, and Mr. Charles E. Shearer, of the class of 1905.

LXI. Notes on *Æther* and *Electrons*.

By C. V. BURTON, D.Sc.*

1. *APHENOMENAL Processes defined*.—There are some processes whose type is such that an observer with his surroundings may be the seat of them without any resulting *phenomena* being manifested to him; that is to say, the processes in question are without influence on the senses of the observer, or upon any instrumental test or measurement which he can make. We may exclude from present consideration such motions and other effects as remain undetected solely by reason of their minuteness, defining as *aphenomenal* those processes which elude observation through the absence of any standard of permanence by comparison with which they may be judged.

Thus absolute velocity in space, if admissible at all as a physical conception, appears to be rigorously aphenomenal.

2. *Absolute Acceleration*.—As a further example, consider a mass of perfectly incompressible substance of uniform density, completely filling an absolutely rigid envelope. We may suppose the incompressible substance to be a deformable solid, or a liquid either possessing viscosity or perfectly frictionless. Let the deformable substance be in motion in any definite manner, subject only to the limitations imposed by its incompressibility and by the rigid containing boundary. At any subsequent time, provided the envelope is without rotation, the relative motions affecting the deformable substance are completely determinate, and independent of any

* Communicated by the Author.

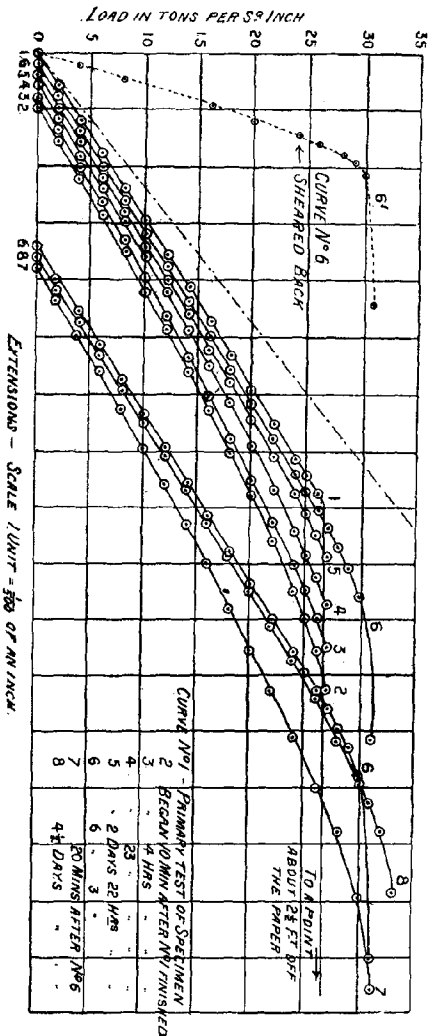


Fig. 1.

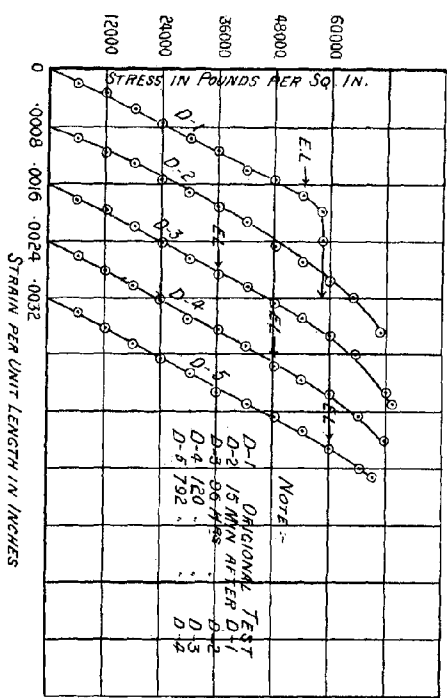


Fig. 2.

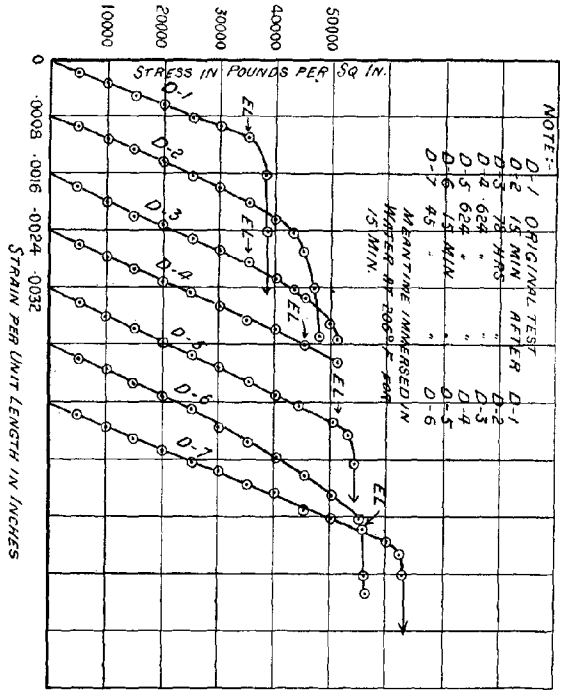


Fig. 3.

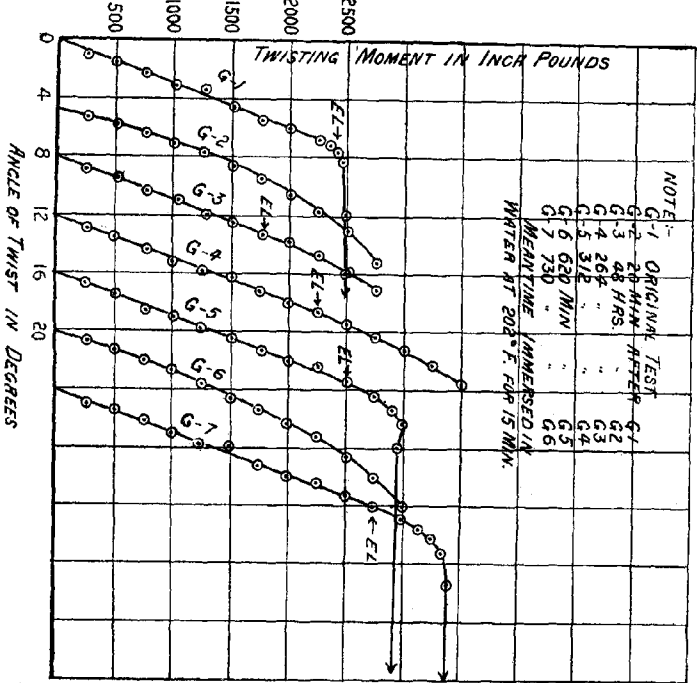


Fig. 4.

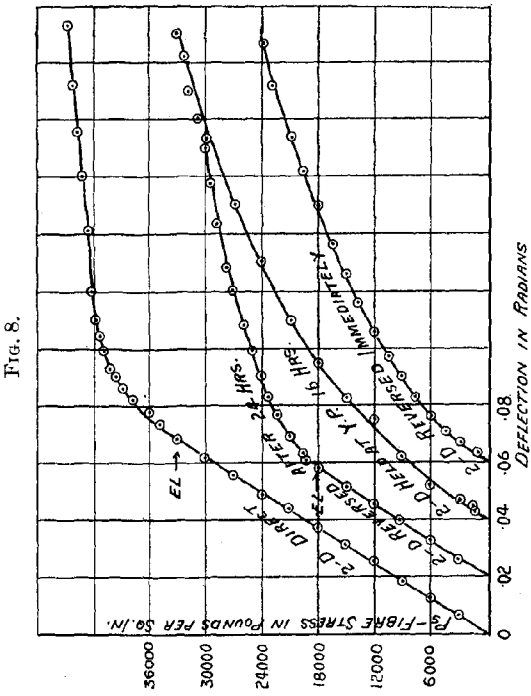


Fig. 5.

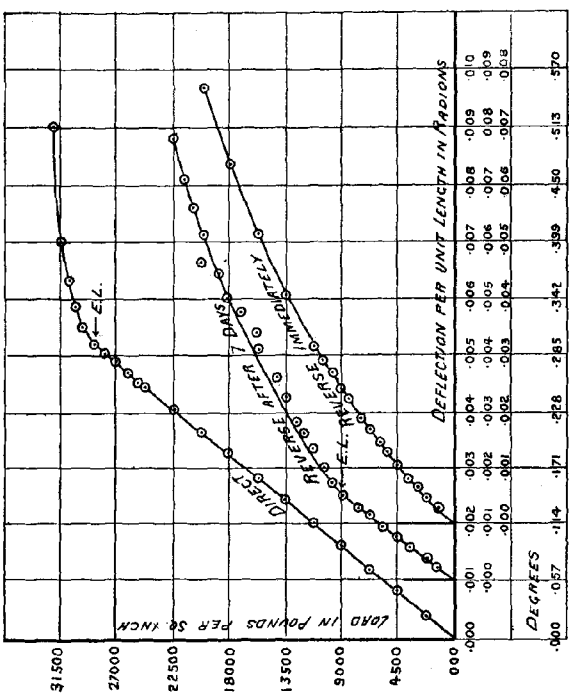


Fig. 6.

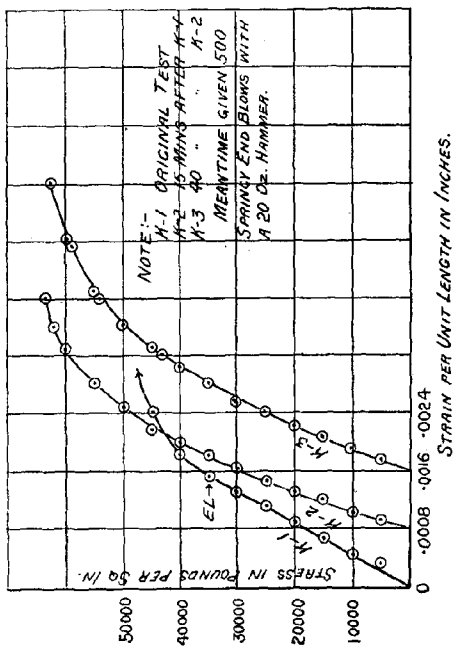


Fig. 7.

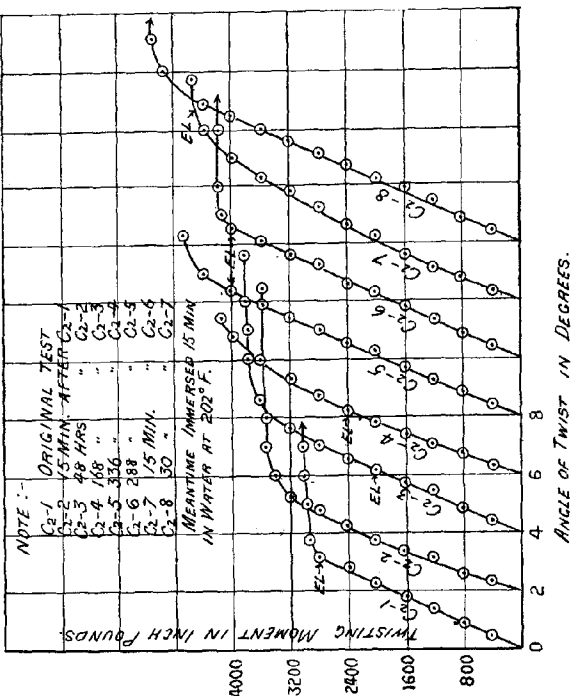


Fig. 8.