SLOW RECOVERY AND PERMANENT SET IN COPPER, ALUMINUM, AND LEAD.

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When a copper wire is strained and the stress is removed there is an instantaneous recovery followed by a slow recovery with time. This slow recovery may be accounted for by the hypothesis that it is due to the recrystallization of the metal. The fact that there is a recovery with time is not new. Even the magnitude of the recovery as a function of time has been investigated experimentally and is fairly definitely known. But so far no one seems to have been sufficiently interested to seek for an explanation of the cause of recovery.

Andrade (1) has done much experimental work on the flow of soft metals under stress. Knowing from the micro-photographic work of Quincke (2), Ewing and Rosenhain (3), and Beilby (4) that when a metal is strained there is a breaking down of the crystallar structure of the metal, he reasons that since the two take place simultaneously the one is due to the other, and he is able to substantiate his theory by experiment, both from observed phenomena of a strained wire and by looking into a microscope and seeing what actually takes place in the metal.

But the work of Quincke, Ewing and Rosenhain, and Beilby does not stop with the observation that the crystallar structure of a metal breaks down under excessive strain. They find that as soon as the stress is removed that the crystals of the metal begin to reform. For copper at ordinary temperatures this process is very slow. But if the temperature is raised, to say three or four hundred degrees the process of recrystallization is exceedingly rapid, almost instantaneous, and the specimen becomes annealed. The object of this paper is to present facts which show that slow recovery is due to recrystallization of the metal.

Plate I shows that an unannealed specimen of copper has a much more decided recovery than an annealed specimen subjected to the same strain. Plate III shows the same thing for aluminium. Plates II, IV and VI show that for all three metals investigated the larger the stress applied, other conditions being equal, the greater the recovery. Plates I, III and V show that the longer the time of applying the stress the greater the recovery, the stresses being equal. It will be noticed from these same curves that per unit of length per unit of stress the amount of recovery of the different metals is in the same order as the temperatures at which the metals anneal. All these facts support the hypothesis that the recovery of a metal after the stress has been removed is connected with the process of recrystallization.

In the first instance the material of a drawn wire that has not been annealed is largely reduced to the amorphous phase. Such crystals and parts of crystals as remain are under strain which is the result of drawing. Most of the strain was relieved when the tension of the drawing process was released. But the fine amorphous particles fill the spaces about the remaining crystals leaving the metal still in a state of strain. Annealing or recrystallization immediately begins and the amorphous particles begin to attach themselves to surrounding crystals. As the crystals build up there is a shrinking in the length of the specimen. This shrinking continues until the more easly occupied spaces are filled, the displacement gradually becoming less and less until it is not detectable. But there is still strain left for not all metals anneal perfectly at ordinary temperatures. When more strain is produced by applying stress there is an agitation of the particles of the metal and the shrinking starts again, as soon as the stress is removed. Since in the drawn wire a large per cent of the metal is in the amorphus phase it is only logical to expect that there would be a greater recovery for a given immediate strain than in an annealed specimen.

It is easily seen from this viewpoint how increased stress and increased time of applying stress produce greater recovery. Starting with an annealed specimen, the greater the stress applied the more crystals there are broken down and the more amorphous substance there is to take part in the process of crystal formation, hence the greater contraction. The same argument holds for increased time of applying stress.

There is no legitimate basis of comparison of the rapidity of contraction of two different metals. A suspended aluminium wire a meter long meets but comparatively little opposition to contraction due to its own weight. A piece of lead wire a meter long suspended by one end, when freshly annealed flows of its own weight. This indicates the great force that must be overcome, in the case of lead, by the forces of recrystallization, even to maintain the original length. Since experimental results show that there is actually greater recovery for lead per unit of length per unit of stress applied, other conditions being the same, in spite of this handicap, than for either copper or aluminium we see how much greater must be the forces that cause the shrinkage in lead. But lead anneals perfectly at ordinary temperatures, aluminium at higher temperatures and copper at still higher temperatures, just the order that must be expected if recovery is to be accounted for by recrystallization. The fact that greatest recovery takes place where greatest activity of recrystallization is involved is a strong point in favor of the hypothesis that the one is dependent on the other.

This idea fits exactly Prof. Michelson's (5) picture of elastico-viscous recovery. The force that causes the shrinkage is an elastic force but produces no instantaneous effect for just the same reason that a rubber band stretched on a block of wood cannot contract to its original length. But cause the block of wood to contract gradually by any means whatsoever and the rubber band follows it. In just the same manner the elastic forces which are contained within the remaining crystalar structure cannot act because they encompass the amorphous phase of the material. But let this phase begin to reform into crystals. It is wedged between the crystals and fills all the spaces between them. As it joins neighboring crystals or forms new ones the original crystalar structure begins to make a readjustment because of the strain which it is under. The more active the amorphous phase is the more rapidly the whole structure contracts.

Such a conception of the state of a metal after strain will account for what Prof. Michelson (5) calls "Lost Motion", the failure of a strained metal to return to its original configuration when the stress is removed. It is found that the more nearly perfect the process of annealing is, the greater is the "Lost Motion". When a wire is stretched the crystals break down and are drawn out in the direction of the length of the wire. The amorphous phase that is produced in the breakdown fills up such crevices as may be created due to the displacement and breaking up of the crystals. When the stress is removed such crystals as remain intact cannot return to their original position because of the presence of the amorphous phase. The broken crystals have lost much of their elastic property. Both of these causes tend to produce a permanent set or permanent elongation in the specimen.

Acknowledgement is made to Prof. Lemon of Ryerson Physical Laboratory for his suggestions and help on this problem. I am also indebted to the Physics Department of Chicago University which provided the equipment necessary.

Bibliography.

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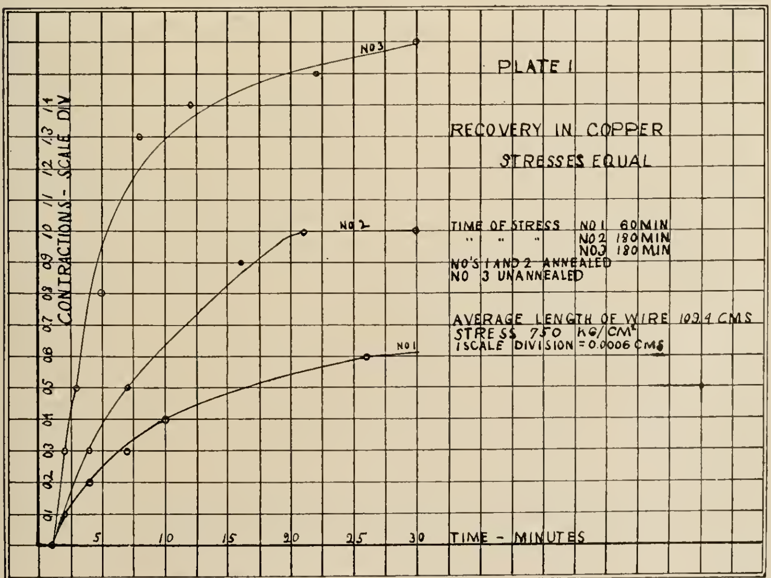

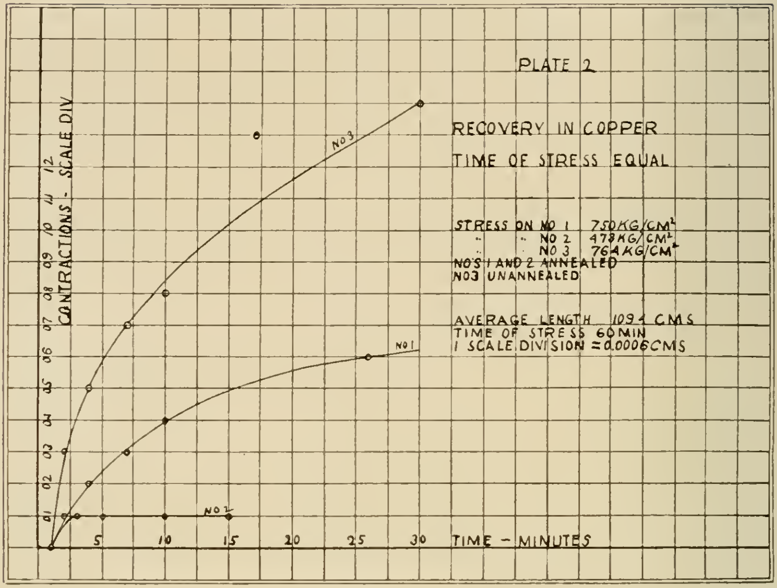
PLATE 2
RECOVERY IN COPPER
TIME OF STRESS EQUAL
STRESS ON NO 1 750KG/CM²
" " NO 2 478KG/CM²
" " NO 3 764KG/CM²
NO'S 1 AND 2 ANNEALED
NO3 UNANNEALED
AVERAGE LENGTH 109.4 CMS
TIME OF STRESS 60MIN
1 SCALE DIVISION = 0.0006CMS
CONTRACTIONS - SCALE DIV
TIME - MINUTES
NO 3
NO 1
NO 2
5
10
15
20
25
30

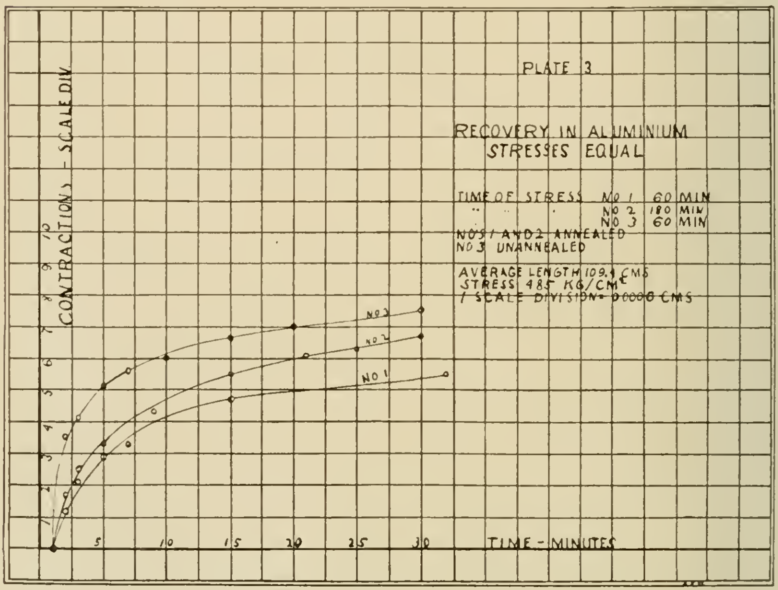
PLATE 3
RECOVERY IN ALUMINIUM
STRESSES EQUAL
TIME OF STRESS NO 1 60 MIN
" " " NO 2 180 MIN
" NO 3 60 MIN
NO'S 1 AND 2 ANNEALED
NO 3 UNANNEALED
AVERAGE LENGTH 109.4 CMS
STRESS 485 KG/CM²
1 SCALE DIVISION = 0.0006 CMS
CONTRACTIONS - SCALE DIV
TIME - MINUTES
NO 3
NO 2
NO 1
5
10
15
20
25
30

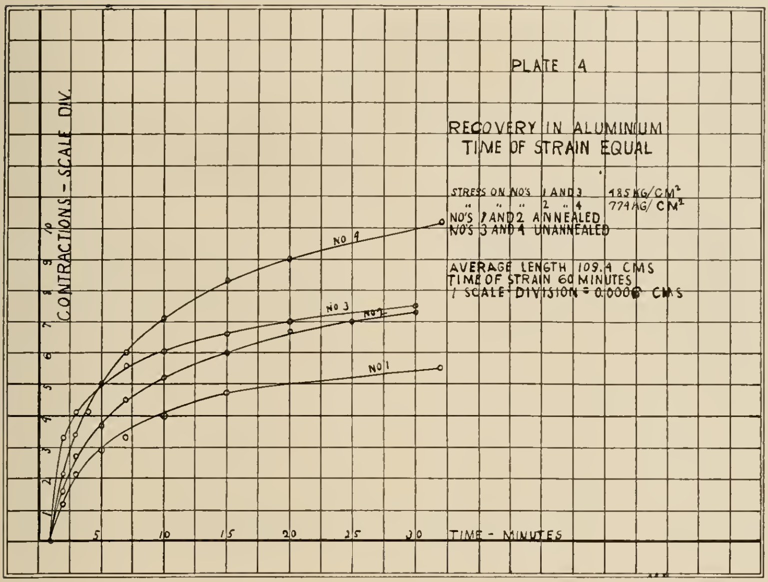
PLATE 4
RECOVERY IN ALUMINIUM
TIME OF STRAIN EQUAL
STRESS ON NO'S 1 AND 3 485 KG/CM²
" " " 2 " 4 774 KG/CM²
NO'S 1 AND 2 ANNEALED
NO'S 3 AND 4 UNANNEALED
AVERAGE LENGTH 109.4 CMS
TIME OF STRAIN 60 MINUTES
1 SCALE DIVISION = 0.0006 CMS
CONTRACTIONS - SCALE DIV.
TIME - MINUTES
NO 4
NO 3
NO 2
NO 1
1 2 3 4 5 6 7 8 9 10
5 10 15 20 25 30

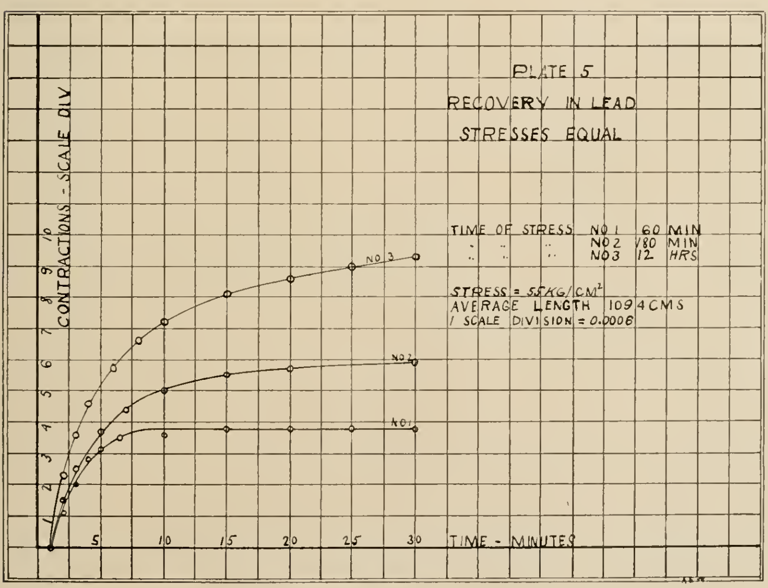
PLATE 5
RECOVERY IN LEAD
STRESSES EQUAL
TIME OF STRESS NO 1 60 MIN
" " " NO 2 180 MIN
" " " NO 3 12 HRS
STRESS = 55 KG/CM²
AVERAGE LENGTH 109.4 CMS
1 SCALE DIVISION = 0.0006
CONTRACTIONS - SCALE DIV
TIME - MINUTES
NO 3
NO 2
NO 1
1 2 3 4 5 6 7 8 9 10
5 10 15 20 25 30

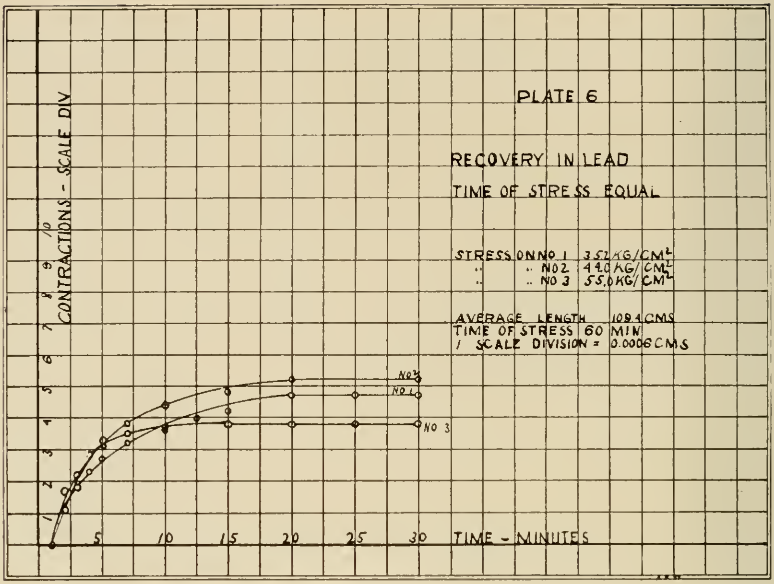
PLATE 6
RECOVERY IN LEAD
TIME OF STRESS EQUAL
STRESS ON NO 1 35.2 KG/CM²
" " NO 2 44.0 KG/CM²
" " NO 3 55.0 KG/CM²
AVERAGE LENGTH 109.4 CMS
TIME OF STRESS 60 MIN
1 SCALE DIVISION = 0.0006 CMS
CONTRACTIONS - SCALE DIV
TIME - MINUTES
NO 2
NO 1
NO 3
1
2
3
4
5
6
7
8
9
10
5
10
15
20
25
30