32. *Some Experiments on Crack Formation in a Glass Plate.*

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1. Using the theoretical results obtained by C. E. Inglis[1] in 1913, A. A. Griffith[2] pointed out the fact that the accumulation of tension stress at sharp corners of crack is the main cause of the growth of that crack in a brittle material, and he also elucidated the rupture phenomenon by the use of energy theory.

Recently Professor T. Terada[3] studied the problem of the crack phenomenon and concluded that this phenomenon was the irregular and irreproducible one and the problem should be studied statistically. From a certain basis concerning their velocities, he classified the cracks in the following two classes:— dynamical crack and statical crack. The latter is such a one that is developed with a velocity which is comparatively small in comparison with the sound velocity of that material; the former is such a one that is propagated with a velocity comparable with the sound velocity of the material. The one is essentially wave phenomenon and the other is governed by the boundary conditions. He also studied the physical nature of the end point of a propagated straight crack with the analogy of electron. In order to set up his theory, he applied the experimental results obtained independently by R. Taguti,[4] S, Suzuki[5] and M. Hirata.[6] Besides the investigations of the above three authors, the result obtained due to Professor S. Fujiwhara[7] may be noted as another experimental study on crack phenomenon in this country.

We are intending to study the problems in the following three steps. The first is on the mechanism of the generation of crack and the

1) C. E. Inglis, *Trans. Inst. Naval Architects*, **55** (1913).
2) A. A. Griffith, *Phil. Trans. Roy. Soc.*, A **221** (1921) & *Proc. 1st. I.N.C. for Applied Mech.*, (1924).
3) T. Terada, *Bull. I.P.C.R.*, **16** (1931), 159~171.
4) R. Taguti, *ibid.*, **10** (1931), 110 (in Japanese).
5) S. Suzuki, *Proc. Phys. Math. Soc.*, Japan, **3** (1921).
6) M. Hirata, *Bull. I.P.C.R.*, **8** (1929), 52 (in Japanese). *ibid.*, **16** (1931), 172.
7) S. Fujiwhara, *Bull. Earthq. Res. Inst.*, **9** (1931), 50, (in Japanese).

growth of the generated crack. The second is on the form of crack, and the third on the velocity of growth of that crack. The first is very complicated, so that we are now contented with the theoretical researches carried out by A. A. Griffith.[8] Secondly the study on the forms of cracks seems to be most interesting to us and there are many problems concerning the forms of cracks. Due to the processes, by which the crack is formed, namely mechanical,[9] heating,[10] electrical[11] etc., applied on a material which may be under initial stress or not, the generated crack has different appearance in each case. The properties and the geometrical form of the material itself and the boundary surfaces are, of course, effective on the formation of crack. Lastly, concerning the velocity of crack Professor K. Sezawa had had, in a former time, the following opinion about the velocity of crack. Referring to the experimental results obtained by late Dr. M. Hagiwara,[12] he stated that the velocity of crack was perhaps limited within the velocity of the elastic wave of the material. From our experiment which is of relatively slow loading-speed, the crack of a material has different velocities according as the magnitudes of the applied loads. In Dr. Hagiwara's experiment the loading speed is nearly instantaneous, so that the elastic deformation is propagated with constant velocity and therefore the crack in pursuit is also transmitted with apparently definite velocity. Needless to say, in the shock phenomenon the shock (elastic) wave is main cause to generate and to grow the crack in the material. If, however, we consider more closely, the crack is not propagated with a definite velocity like elastic waves of the material, but rather the growth of crack is a discontinuous phenomenon with respect to time in the strict sense of the word.

I. General Principle of Experiment.

2. The principal parts of experimental arrangement consist of a Mohr's universal testing machine, a specially designed dynamometer,

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8) A. A. Griffith, *loc. cit.*

9) R. Taguti, *loc. cit.*

10) M. Hirata, *loc. cit.*

11) T. Terada, M. Hirata and R. Yamamoto, *Proc. Imp. Acad.*, Tokyo, 8 (1932).

12) The elaborate results of Dr. M. Hagiwara's experiments were not published in his lifetime. His experiment is as follows: the principal parts of his experimental arrangement consist of a rifle, a testing glass plate, spark gaps and the photographic apparatus. At the instant when a bullet penetrates the glass plate, instantaneous photographs are taken.

a flat steel plate, and test pieces. In order to discriminate the corners of cracks, we used glass plates, of which the thicknesses were 1∼2 millimetres, as test pieces. The arrangement is shown in Fig. 1.

By the action of Mohr's testing machine the strain energy is accumulated in the glass plate. The glass plate has flat surfaces, the lower surface being contacted with the flat steel base and the upper surface is in a point-contact with a steel ball, of which the diameter is of 1/16″. The mirror, the scale and the telescope system is also employed for the estimation of the load applied to the glass plate from the loading apparatus. Marten's extensometer is attached to the dynamometer as shown in Fig. 1. The load-deformation characteristic of dynamometer is shown in Fig. 2.

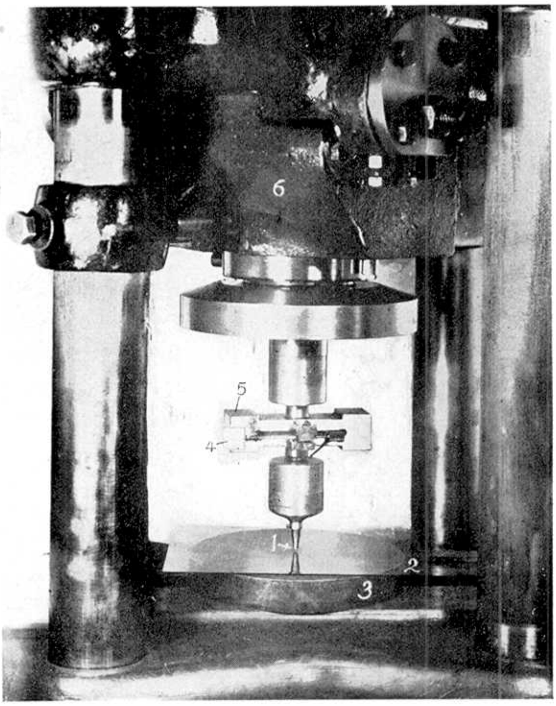

Fig. 1. Experimental arrangement.

[1 : steel ball, 2 : glass plate, 3 : steel plate, 4 : Marten's mirror, 5 : dynamometer.]

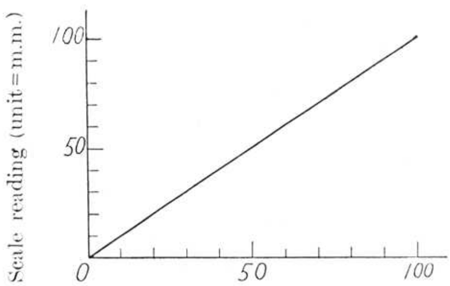

Fig. 2. Load-deformation characteristic ofdynamometer.

As the depression of the surface of glass plate due to the ball was too small to measure its magnitude, the rough magnitude of the depression was measured by counting the number of revolution of the handle of the Mohr's apparatus, neglecting the slip of the transmission mechanism. The loading speed was maintained nearly constant as possible during each experiment.

We have divided the crack phenomena in three parts occurring in different stages of its growth as well in different regions of the glass plate:— The part occurring in the vicinity of the origin, the part forming radial crack and the part taking place at the edge of the plate. In the second part the velocity of the growth of radial crack became apparently constant. In that stage the relation between the growth of crack and the applied load was obtained. In the part occurring in the vicinity of the origin, where the steel ball was in a point-contact with the glass plate, the state of the plate, from which the radial cracks were originated, was observed. In the third part the cracks occurring near the edge of the glass plate were studied.

II. The Part Occurring in the Vicinity of the Origin.

3. As the cracks in the upper surface of the glass plate were very feeble, we used a microscope for this study.

When we applied the load gradually, the surface which was in a point-contact with the steel ball was gradually deformed elastically. If the load exceeded a certain limit which perphaps corresponded with the elastic limit of glass plate, the permanent indent due to the steel ball was observed microscopically when the load was released. Yet we could not see any type of crack in this state. When the load was more increased, perfectly circular crack, of which the diameter was nearly 0·2 millimetres, was found in the upper surface of glass plate. (See Fig. 3.) At some increase of the load the circular crack of larger diameter was visible and this circular crack was concentric with the former circle and took its position again in the upper surface of the plate. (See Fig. 4.) In this state the former crack disappeared in almost all occasions.

With the more increase of load we could observe a number of spiral cracks around the bounding circle and this number increased with the increase of load. (See Fig. 5, 6, 7, 8[13] & 9.) The crack of this type was named "*spiral crack*" for the convenience, and the former circular "*Circular crack*".

13) C. V. Raman took the same photograph as that of Fig. 8. His experimental method was a dynamical one.

C. V. Raman, "Percussion Figures in Isotropic Solid," *Nature* (1919).

When the *spiral cracks* grew fully, the Newton rings which had been born in advance could be seen distinctly around these cracks. (See Fig. 6, 7, 8.) The number of the Newton rings increased with the increase of load. These rings were the effect due to another type of crack whose form might also be conical. We called this type of crack "*conical crack*". Nearly in this stage we could see another traces of cracks which seemed to run on the surface of *conical crack* like feathers. We called these "*feather cracks*". (See Fig. 5, 6, 7, 8.)

After the growth of these four types of cracks, another type of series of cracks was suddenly branched off nearly from the centre of the *circular crack* and in the interior of the glass plate with feeble sound. These cracks had the nature to grow radially from the loaded position nearly in straight line forms. We called them "*radial cracks*" for convenience. The *radial cracks* ran along the bottom surface of the plate which was in contact with the steel plate. (See Fig. 9.)

The *radial cracks* in their initial stage produced in the plate accompanied with feeble sound had large velocities of transmission, so that their natures could not be well studied: merely their forms and depths could be studied. The *radial cracks* made their forms appear in the bottom surface of the plate, but they did not appear in the upper surface of glass plate. This fact can be seen from the photographs of the *radial cracks* in the vicinity of the origin. The plan views of *radial cracks* are illustrated in Fig. 10b, 11b, 12. Fig. 10b, 11b are the views from the bottom sides and Fig. 10a and 11a that from upper sides. [Upper side corresponds with the surface of the glass plate which is in point-contact with steel ball.] It is also the noteworthy fact[14] that the *radial cracks* had no direct connections with the cracks of other types that were found in the upper surface of glass plate.

The most interesting type of cracks among all various cracks formed in the upper surface of the plate in the vicinity of the origin is the *conical crack*. This type of crack developed in the interior of the plate deeper than other three types. On examining by means of microscope, it was indeed found that the cracks such as *circular*, *spiral* and *feather cracks* resided in the above portions of the surface of the *conical crack*. The *feather cracks*, however, seemed to be on the very surface of the *conical crack* as we have described in the first part of this section. We understand by the patterns of the Newton rings that the breadth of

14) This fact could be ascertained by flowing a drop of ink on the upper surface of the glass plate.

conical crack becomes thiner and thiner towards the outer part of that crack, and it is, of course, of the order of the wave length of light.

When we estimated by microscope the distances between the upper surface of glass plate and the suitable points of the *conical crack*[15] as well as that of the *feather cracks*, we confirmed, together with the patterns of Newton rings, that the *conical crack* superposed with *feather cracks* grew almost in the form of a cone. Now we examine these facts in the following two examples. The observed points a, c, d, e, f, g, h, i, j in Fig. 13b correspond with those in Fig. 13a which schematically shews the photograph Fig. 9. Again the points a, b, c, d, e, f, g, h, i in Fig. 14b correspond with those in Fig. 14a which shews schematically Fig. 15c. The distances at the points e, d, j, h, i in Fig. 15a, and e in Fig. 14, which are not situated on the *feather cracks*, are determined

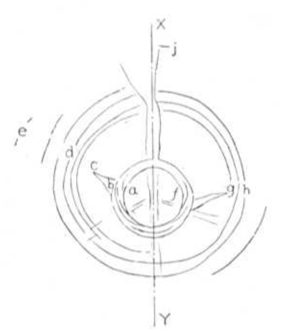

Fig. 13a. (Schematical figure of the photograph Fig. 9.)

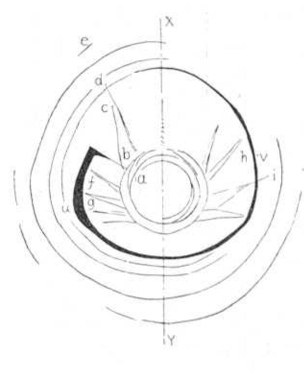

Fig. 14a. (Schematical figure of the photograph Fig. 15c.)

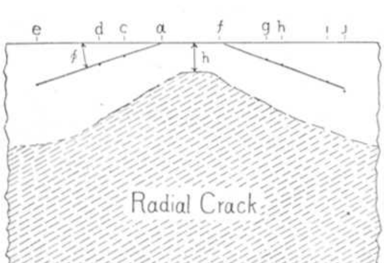

Fig. 13b. Profile of *conical* and *radial crack*.

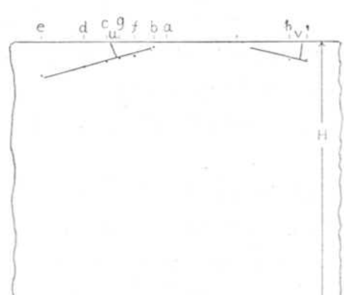

Fig. 14b. Profile of *conical crack*.

15) We confirmed the position of the *conical crack* by flowing a drop of ink on the upper surface of the glass plate.

by flowing a drop of ink in the *conical crack*. The results thus obtained in Fig. 13b and 14b shew us that the observed distances appear to give a nearly straight profile of a cone.

By the method above mentioned, the angle ϕ[16] between the upper surface of glass plate and the surface of *conical crack* was estimated, and the results are shown in the following table. (Table I.) From this

Table I.

No.	Load	H	ϕ	h
54	15 Kg	1·40 mm	21°	
52	20	1·41	17	
58	25	1·57	14	
78	33	1·40	19	0·176 mm
75	36	1·80	14	
6	40	1·50	12	
86	41	1·60	18	
47	30			0·167
44	30·5			0·201
45	32			0·173
D				0·164
F				0·167

H: thickness of glass plate.
ϕ: angle between the upper surface of the glass plate and the surface of *conical crack*..
h: shortest distance between the upper surface of plate and the *radial crack* at the region of loaded position. (See Fig. 12b.)

table, we understand that the magnitude of ϕ is almost independent of the magnitude of applied load and the thickness of glass plate, and it is limited between 10° and 20°. The mean value of the angle ϕ is 15°.

Comparing the thickness of glass plate with the dimension of *conical crack* in Fig. 13b and 14b, we find that the cracks such as *circular*, *spiral*, *feather* and *conical* are almost taking their places in the upper surface of glass plate.

Radial crack is schematically shown in Fig. 13b by the hatch.

As we have described, the four types of these cracks in the vicinity

16) To measure this quantity, the refractive index of glass plate was taken into account.

of the upper surface of glass plate have the connections with each other, but they have no direct connections with *radial cracks*.

Again, the interesting fact is that the cracks named *circular*, *spiral*, *feather* and *conical* are distributed almost symmetrically about a line passing through the center of the *circular crack* and parallel to the plane of the plate. See Fig. 5, 6, 7, 8, 9, and 15. Two systems of *feather cracks*, each with its proper sense of extension, meet at this line of symmetry. This phenomenon is not due to the effect of the arrangements of the experimental instruments.

Another point to be remarked is that we discovered a new type of crack[17] lasting long after the applied load was taken off. (See Fig. 15a, 15b, 15c, 16.) This new type of crack developed vertically from the surface of *conical crack* in the forms of spiral or near circle between the upper surface of the glass plate and the conical surface of *conical crack*. (See Fig. 14b.) Fig. 14b indicates this fact clearly. Fig. 15a was taken immediately after the load was taken off, and Fig. 15b and Fig. 15c were taken respectively one and two days after the applied load was released. The form and the breadth of the fringes of Newton rings vary with the growth of this special type of crack. We can see from this fact that the breadth of *conical crack* varies according as the crack of this special type grows in the glass plate.

III. The Part Forming Radial Cracks.

4. In this part we shall study the nature of the *radial crack* at distances which are not so near the origin.

When the load reaches point C in Fig. 17, the *radial cracks* suddenly appear accompanied by a feeble sound. No sooner the load decreases to the point D instantaneously from the point C than the *radial cracks* appear, and then the feeding of the load should be stopped. From the stage D, the load decreases exponentially during a short time and attains to a constant value (HI) finally. At this

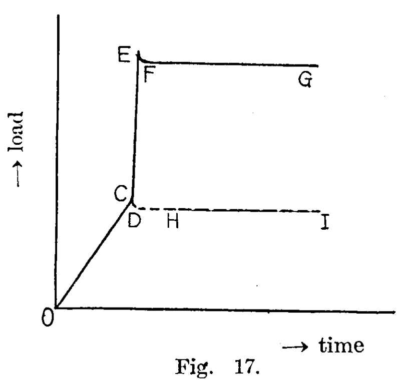

Fig. 17.

17) Prof. T. Terada has also found in his experiment.
T. TERADA, M. HIRATA and R. YAMAMOTO, *loc. cit.*

stage the velocity of the growth of crack becomes apparently constant, *i. e.*, the *radial crack* which is started from the point in the plate near the position where the steel ball is in a point-contact has a large velocity for a moment, but after one or two seconds the apparent velocity tends to attain a constant value, which is smaller than that of the initial velocity. The growth of the *radical crack* in this state depends only on the magnitude of the strain energy given in the glass plate. As the order of the velocity of *radial crack* is a few millimeters per minute, the end point of the growing *radial crack* is readily observed. We vanished beforehand the glass plate with lack film uniformly and in experiment we marked with a sharp pencil on the very ends of the growing *radial cracks* successively. The growth of the *radial crack* is not strictly continuous with time, and therefore the apparent velocity in each state of the growth can only be determined by the above method. Using this method, we obtained the apparent extensions of cracks and the apparent velocities of them. And the results shew us that the velocities, the numbers of cracks and the load are in a certain relation which may be reasonable from common sense. But the velocities thus obtained were very small, and we could not obtain the fine result of experiment.

Now to study the natures of these quantities more distinctly, we made the following experiment. After the load reached a certain limit, which corresponded with the stage of the formation of the first *radial cracks* in the plate with a feeble sound, we instantaneously increased the load to the limit in which a second feeble sound was heard. In Fig. 17, E is the point corresponding to this second stage. After the point E was reached, the feeding of load was stopped, and the load attained

Table II.

Number of *radial cracks*=2			
time	A	time	B
1′ 0″	24·0 mm	1′ 0	19·2 mm
40	28·7	50	24·0
2′ 0	30·4	2′ 10	25·2
20	31·0	40	27·1
55	32·7	3′ 35	29·4
3′ 25	33·7	5′ 10	32 0

(*to be continued.*)

Table III.

Number of *radial cracks*=3			
time	A	B	C
35″	21·0 mm		
1′ 25	24·9	29·7 mm	
2′ 0	26·4	31·6	
30	28·0	3·33	
3′ 0	29·5	34·0	
4′ 0	31·2	36·0	32·0 mm
5′ 0			34·5
5	34·6	38·1	

(*to be continued.*)

Table II. (*continued.*)

Number of *radial cracks* = 2

time		A	time		B
		mm			mm
4′	0	34·6	6′	43	33·7
5′	0	36·1	7′	32	36·6
6′	0	37·7		55	38·2
7′	12	39·5	8′	32	40·0
8′	0	41·2	9′	0	41·9
	42	44·0		45	43·4
9′	25	45·6	10′	0	44·3
10′	0	46·9		30	45·4
	30	47·9	11′	0	47·0
11′	0	49·2	12′	0	50·0
	30	50·8		30	51·2
12′	0	52·0	13′	0	53·0
	30	53·1		30	54·4
13′	0	54·8	14′	0	55·8
	30	56·7		30	57·2
14′	0	57·8	15′	0	58·8
	30	59·3		30	60·9
15′	0	61·3	16′	0	63·0
	30	63·9		15	65·0
16′	0	66·4		30	66·6
	15	68·0			
	30	70·0			

Table III. (*continued.*)

Number of *radial cracks* = 3

time		A	B	C
		mm	mm	mm
6′	0	36·0	40·0	36·1
7′	0	38·0	41·5	38·0
8′	0	40·5	43·0	40·0
	30	41·9		
9′	0	43·1	44·6	
	12			43·2
	30	43·9		
10′	0	45·1	45·5	
	24			45·9
11′	0	47·8	46·2	48·0
12′	0	50·2		50·0
13′	0	53·4	48·0	
	25			54·9
14′	0	56·3		
	30			58·6
15′	0	59·7		
	30		50·3	62·0
16′	0	63·1		64·0
	30	65·1		66·4
17′	0	66·8		68·5
	30	69·2		70·5
18′	0	71·9	53·8	72·9
	30	74·0		75·2
19′	0	76·6		
	19		56·4	78·2
	30	79·0		81·0
	50		58·8	
20′	0	82·0		84·5

to a constant value (FG) as shown in Fig. 17. Under this condition, we obtained the apparent extensions of cracks as shown in Table II and III. And the following two figures (Fig. 18[18]) and Fig. 19) are obtained by the usage of Table II and III. Using the nearly straight parts of the curves in these figures, the apparent velocities of them are easily found. Thus we obtain the following table in which the load, the numbers of *radial cracks* and the apparent velocities are tabulated. (Table IV.) Table IV gives Fig. 20 in which the results of this experiment are plotted. In this figure the ordinate indicates the velocity of *radial crack*, while the abscissa the load, and the parameter of the curves is the number of the generated *radial cracks*. Of course, the *radial cracks*

18) The results in this figure correspond with the glass plate shown in Fig. 25.

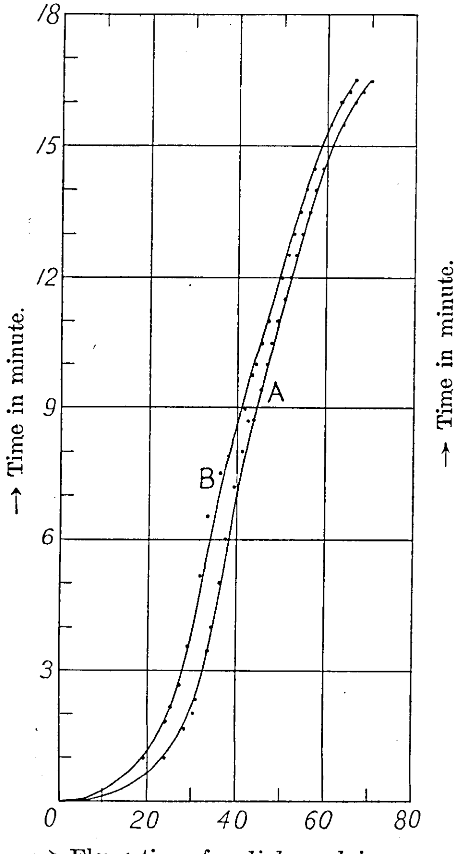

Fig. 18.
(Two *radial cracks* A, B.)

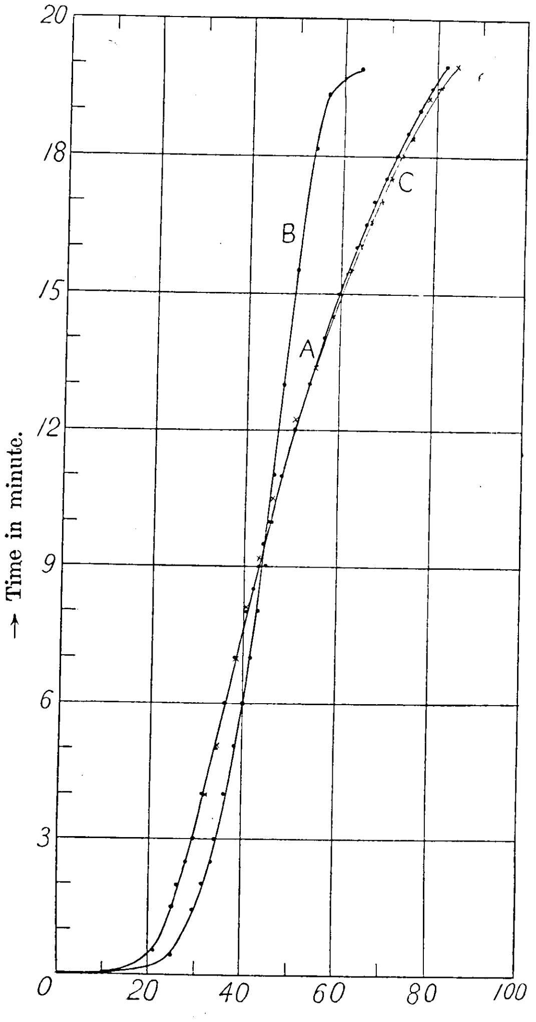

Fig. 19.
(Three *radial craks* A, B, C.)

which did not extend to the region of the general *radial cracks* were not taken into account. From Fig. 20, we can understand that, when the strain energy given in the glass plate is increased, the velocity of *radial crack* is increased, and nearly proportional to the square of the applied load. When the numbers of *radial cracks* increase, the apparent velocities of them decrease.

Fig. 18, 19, as we have described, shew the relation between the

Table IV. Apparent velocity of *radial crack*.

Load	No.	*Radial Cracks*					
		Total Number	A	B	C	D	E
kg. 40	7	4	0·02	0·02	0·02	0·02	—
48	33	2	1·65	1·7	—	—	—
50	10	2	2·0	2·5	—	—	—
52	29	2	—	0·7	1·3	—	—
60	32	2	5·0	2·4	—	—	—
60	25	2	—	1·1	1·1	—	—
60	21	3	2·6	2·3	2·6	—	—
65	49	2	3·6	3·6	—	—	—
70	26	2	2·3	3·5	—	—	—
70	41	3	2·6	2·5	2·6	—	—
70	47	3	3·4	0·6	3·4	—	—
72	48	4	8·7	8·7	3·2	3·2	—
75	40	4	0·8	4·2	5·0	—	0·5
75	34	2	6·2	6·6	—	—	—
90	39	3	5·2	5·2	5·2	—	—
100	44	2	—	5·3	6·0	—	—
100	45	3	5·0	5·0	5·0	—	—
100	51	3	3·0	3·0	3·0	—	—

{ Load in kg.
Unit of the apparent velocity of *radial crack* in m.m./min.

elongation of *radial crack* and time, and the curves in these figures are apparently straight and apparently continuous. As we have discussed in the preceding section, we know that these are merely the apparent values. In the strict sense of the word, the elongation of the *radial crack* is not continuous with time.

In the surface of a *radial crack* of a broken glass plate, we saw the traces of a number of sharp semi-circular figures as shown in Fig. 21. At the places of these traces the *radial crack* seemed to stop its growth for a moment. By marking with a pencil at the stopping points in the growing state of *radial crack* and comparing these marked points with the traces of semi-circular figures in a broken plate, we confirmed this fact well.

The general forms of the *radial cracks* were very simple and nearly

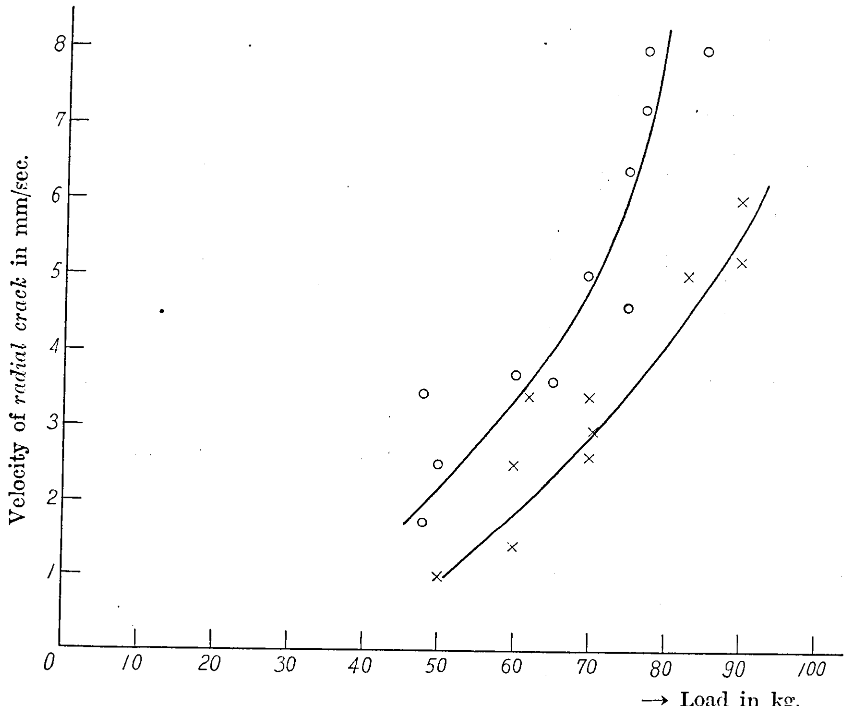

Fig. 20. (○ two *radial cracks*. × three *radial cracks*.)

straight as shown in Fig. 22, 23, 24, 25.

The numbers of *radial cracks* produced in the plate are of important meaning in studying the properties of cracks, and they were, in our case, two, three, four and five. The case of four cracks was very rare. In the case of five cracks, they were generated only in the vicinity of the origin, and they could not extend to farther distances. And the cases of two and three *radial cracks* were very frequently observed.

IV. Radial Cracks at the Edge of Plate.

5. When the *radial cracks* reach near the edge of the plate, their velocities are increased suddenly, and as soon as they reach the edge, a perfect crack extending between the edge and the origin is formed. As we have discussed in the preceding section, the *radial crack* did not appear in the upper surface of the glass plate in its growing state. When the *radial crack* reached the edge, its reflected passage was along

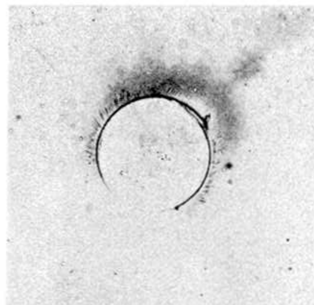

Fig. 3. Circular Crack. ×69
(Load 13 kg.)

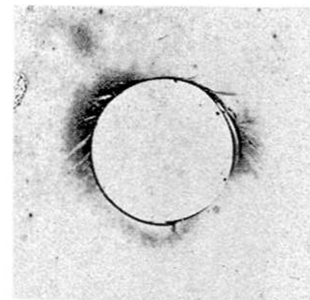

Fig. 4. Circular Crack. ×69
(Load 13 kg.)

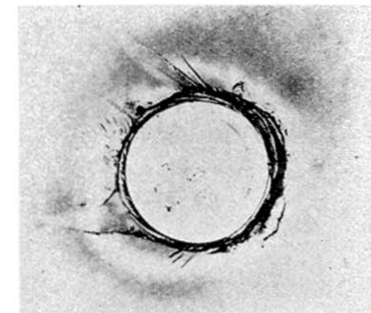

Fig. 5. Spiral Crack, Feather Crack. (Load 13 kg.) ×69

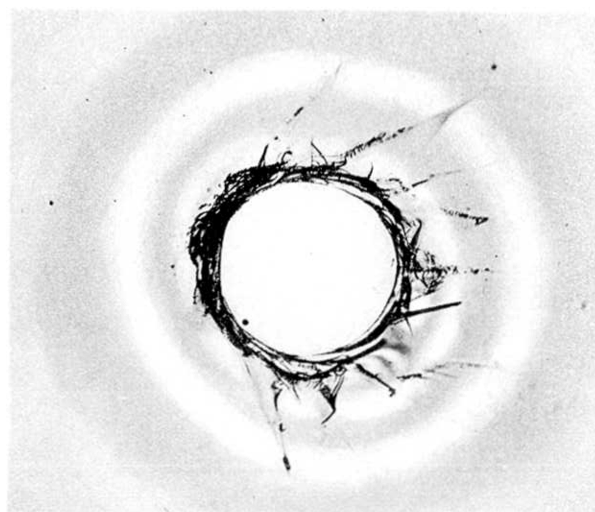

Fig. 6. Spiral, Feather and Conical Cracks. ×69
(Load 30 kg.)

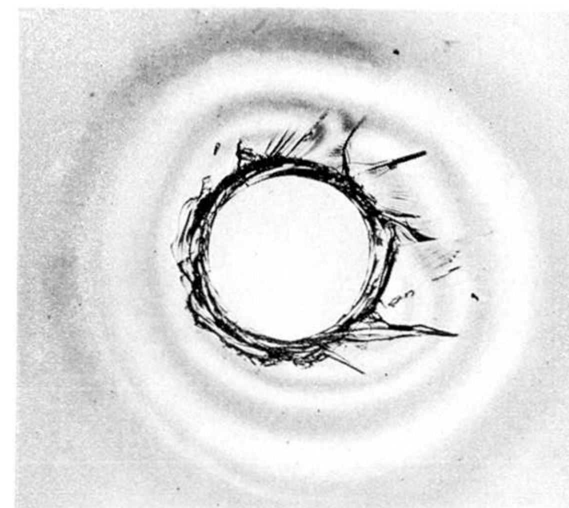

Fig. 7. Spiral, Feather and Conical Cracks. ×69
(Load 25 kg.)

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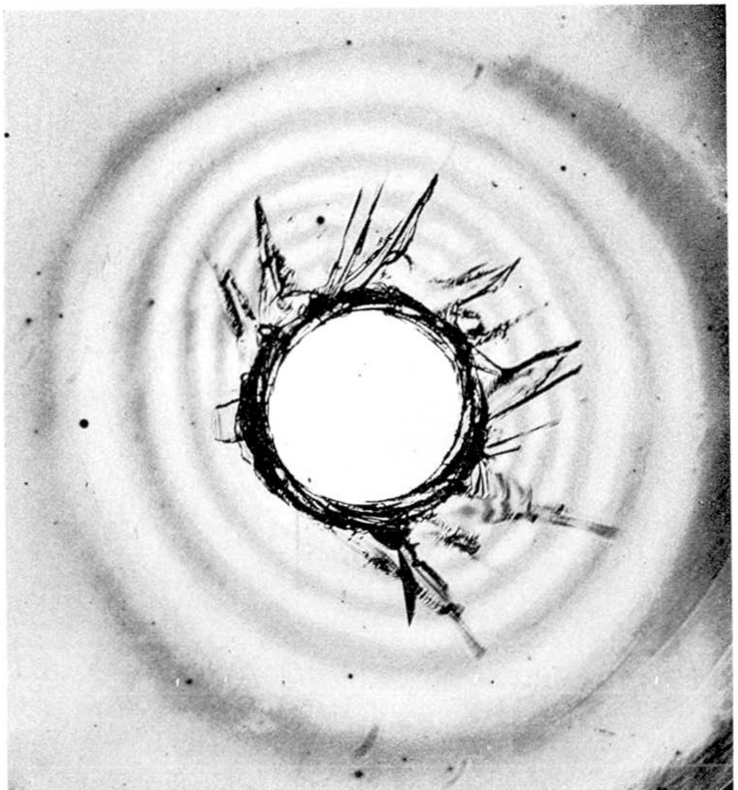
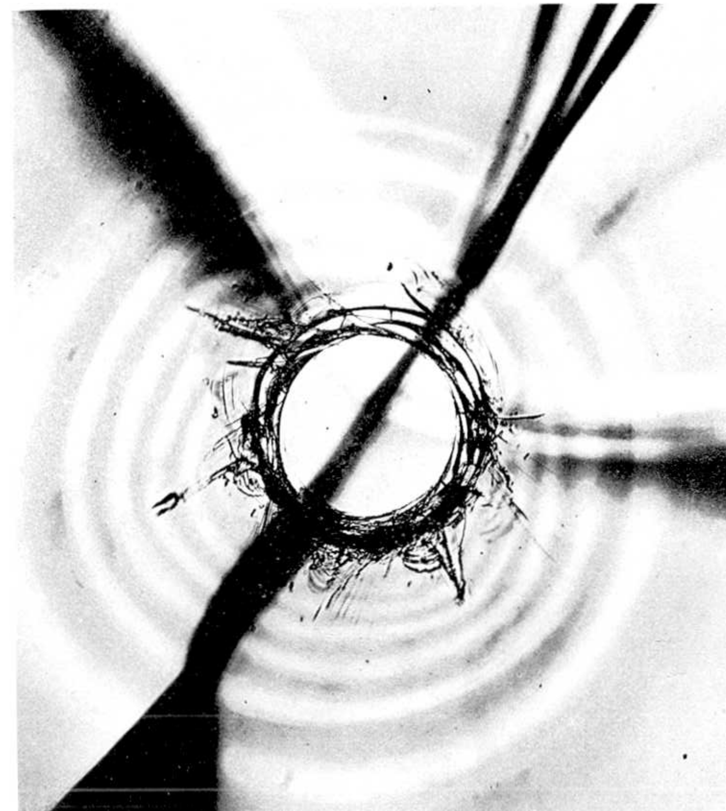


×69

Fig. 8. Spiral, Feather and Conical Cracks. (Load 40 kg.)



×69

Fig. 9. Spiral, Feather, Conical and Radial Cracks. (Load 33 kg.)

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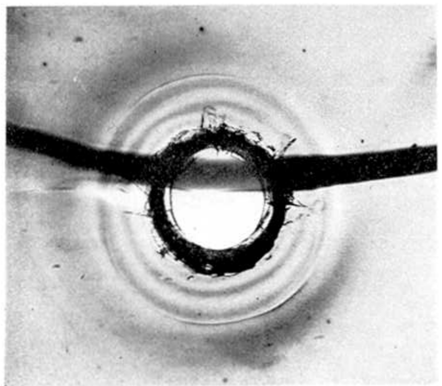


Fig. 10 a. ×35

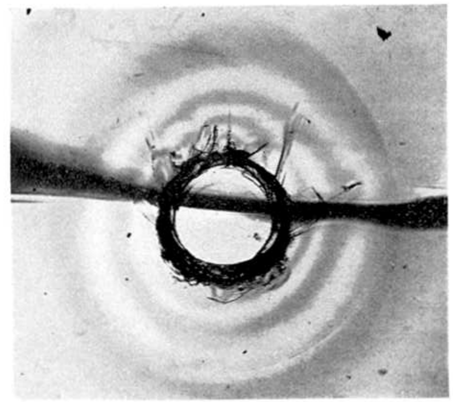


Fig. 11 a. ×35

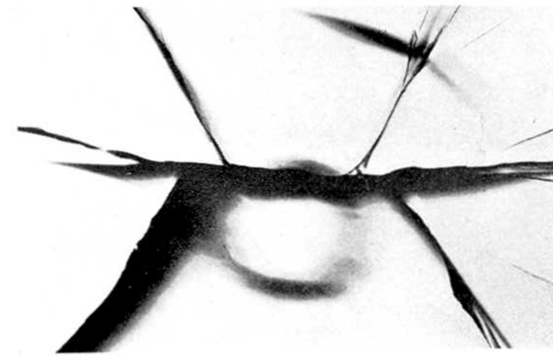


Fig. 12 ×35

Fig. 10. b ×35

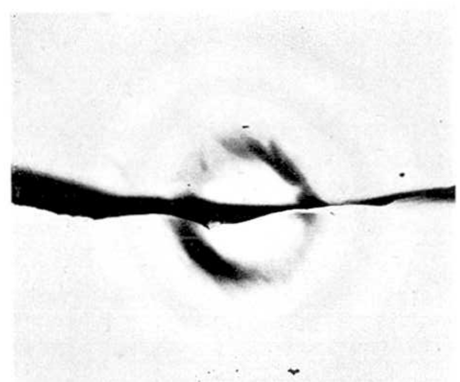
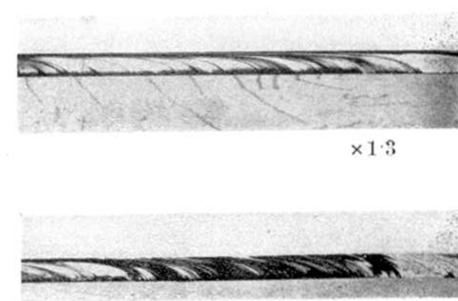


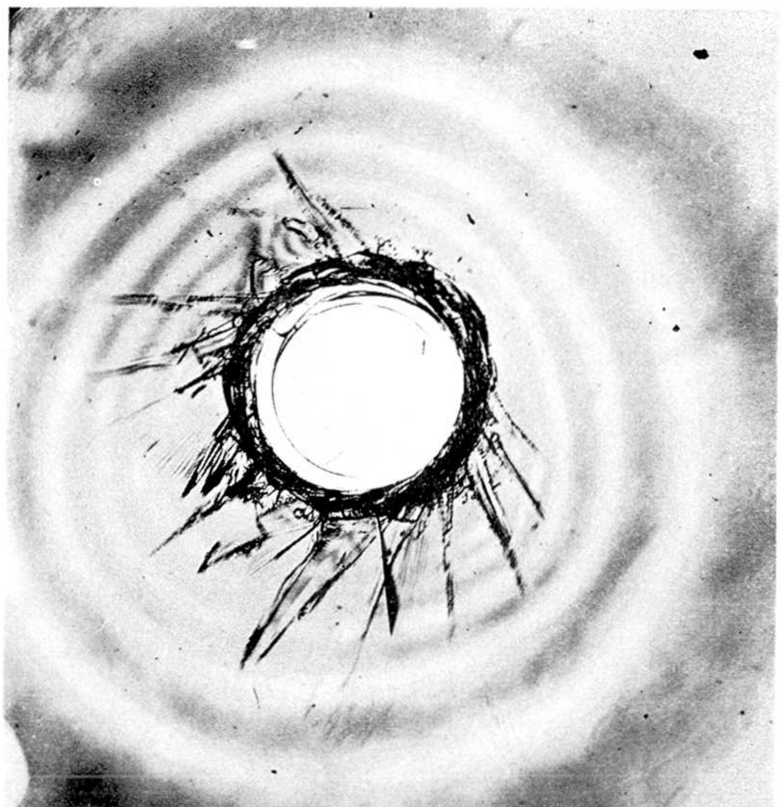
Fig. 11 b. ×35



×1·3

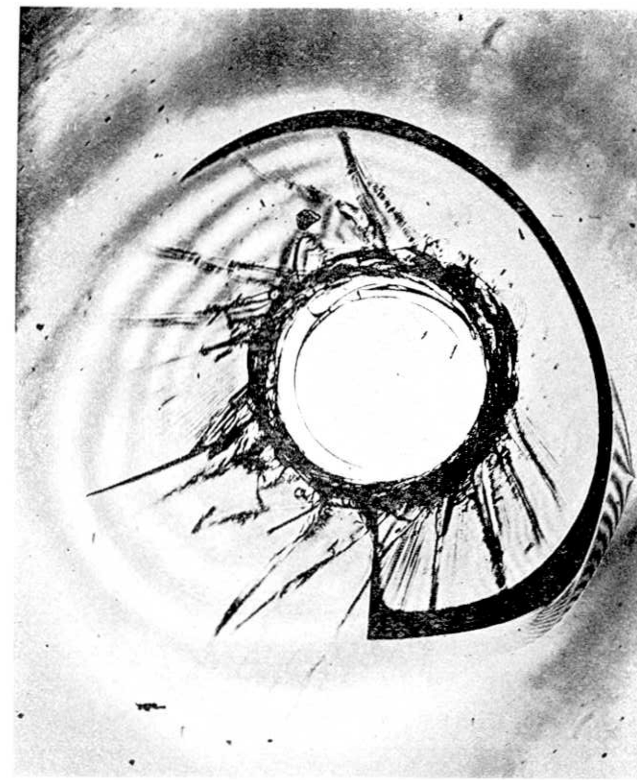
×1·3

Fig. 21. (The surface of Radial Crack of a broken glass plate.)



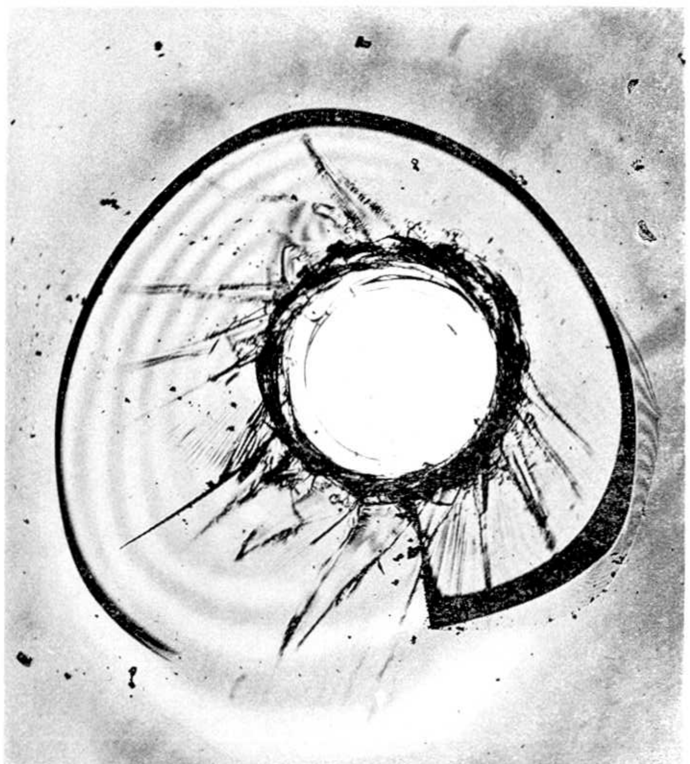
×69

Fig. 15 a. (Immediately after the load was taken off. Load 41 kg.)



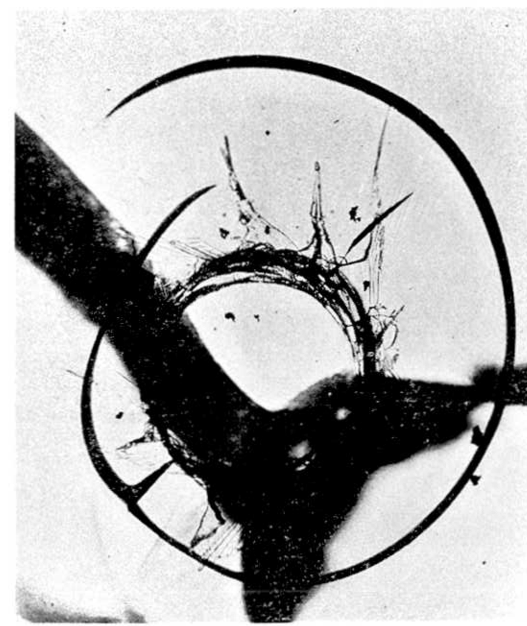
×69

Fig. 15 b. (Same as Fig. 16 a, after one day.)



×69

Fig. 15 c. (Same as Fig 15 a, after two days.)



×69

Fig. 16

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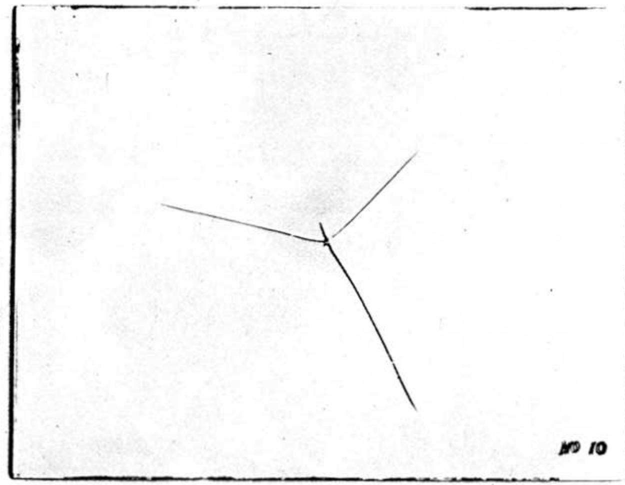

Fig. 22. (Load 50 kg.) $\times \frac{1}{2\cdot5}$

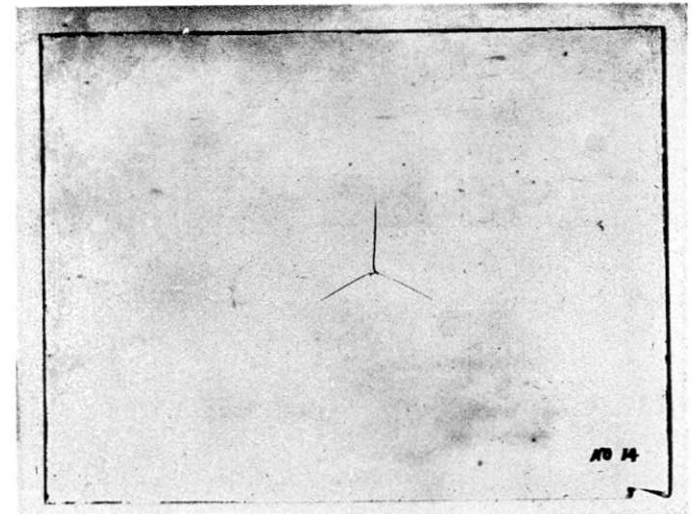

Fig. 23. $\times \frac{1}{2\cdot5}$

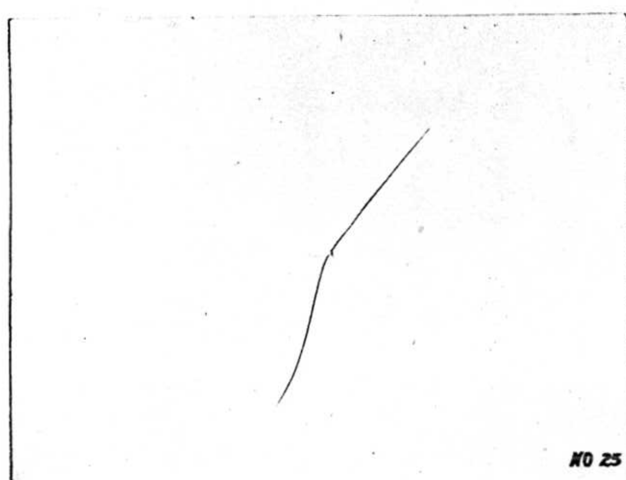

Fig. 24. (Load 60 kg.) $\times \frac{1}{2\cdot5}$

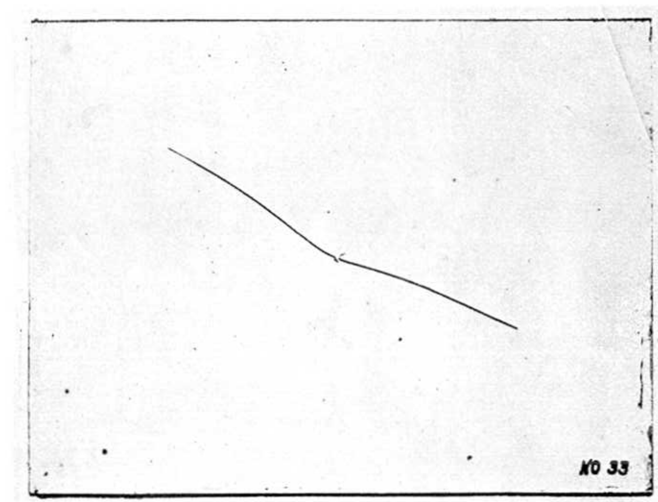

Fig. 25. (Load 48 kg.) $\times \frac{1}{2\cdot5}$

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the upper surface, and it instantaneously reached near the position where the steel ball was in a point-contact.

Fig. 26 and 27 shew these mechanisms schematically. When the *radial cracks* started from 0 and were propagated in the directions of OA, OE and OF along the bottom surface of the plate, and one of the *radial cracks* such as OA reached the edge AG of the plate, it was reflected in the directions of AO' instantaneously along the upper surface of the plate. The path (AO') of the reflected *radial crack* is not necessarily coincident with that of the original *radial crack* (OA). Therefore the section of the crack at XY in Fig. 26 has the shape as represented by Fig. 27. In Fig. 27, I, H correspond with I, H in Fig. 26.

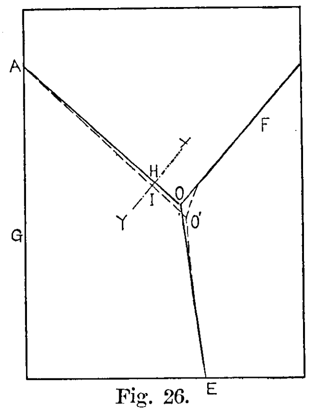

Fig. 26.

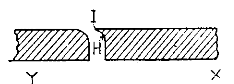

Fig. 27.

Concluding this paper, the authors' cordial thanks are due to Professor T. Terada and Professor K. Sezawa for their kind advices and encouragements during the course of this experiment.

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32. 硝子板のワレメに就て

地震研究所 {西村源六郎 / 高山威雄}

ワレメに關しては、ワレメの出來方、ワレメの成長の機構の研究、ワレメの形の研究等があげられるのであるが、著者達は硝子板（厚さ 1 mm.～2 mm.）を鐵板の上におき、直徑 1/16″ の ball で靜荷重をじよじよにかける時、生ずるワレメの形や成長の仕方等に就て、研究してみた。深い理論をたてる迄には今の所行かないが、將來の研究を進める第一步として、此の種の研究に多少でも參考になる所があれば幸甚である。
