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DEVELOPMENT OF A PIPE CUT AND SEAL DIE

E. EUGENE WADE

ABSTRACT

A die has been developed which will cut and seal the severed ends of 1 1/2-in. schedule 80, 347H stainless steel pipe. Some development work has been done on dies for use on 1 1/2-in. outside diameter x 0.065 wall tube. Very limited work has been done on dies for use on 2 1/2-in. schedule 160 pipe.

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E. Eugene Wade

1. Introduction

The development work described in this report was done primarily to enable the operator of gas-cooled loop No. 2 in the Oak Ridge Research Reactor to remotely cut the loop piping, and in the same operation, to seal the severed ends. This will be necessary because the loop is to be operated with fission products circulating in the loop piping.

Work was started on November 8, 1960. Experiments were done on small tubes to determine if simultaneous cutting and sealing were possible. It proved to be, and a die was made for 2 1/2-in., sched.-160 pipe. During fabrication of this die, requirements of the No. 2 loop were altered, and all later work was done on 1 1/2-in., sched.-80 pipe. A die for 1 1/2-in., sched.-80 pipe has been made which can be used on the loop piping.

2. Conclusions

It is possible to cut pipe with a one-stage die so that spring-back will cause the severed ends to be sealed to such a degree that partial evacuation of the loop piping system will be practical.

The quality of the seal obtainable depends on the pipe diameter, wall thickness, material and material condition, and lubrication. It is probable that other pipe factors also affect the seal. The material and wall thickness must be such that the wall can be bent back upon itself without fracture.

A two-stage die which flattens the pipe in one operation and cuts it in another will give a better seal than a one-stage die and will require about one third less force.

3. Results

3.1. 1/2-in.-o.d. × 0.065 Wall Type 347 Stainless Steel Tube. The material of the loop piping will be type 347H stainless steel and, prior to cutting, may have been held at a temperature of 1350°F for weeks or months. For practical reasons, the test pieces were of type 347 stainless steel which had been heated in 5 min to approximately 1400°F and allowed to cool slowly in air.

Flow rates and related information are given in Table I.

3.2. 2 1/2-in., Sched.-160, Type 347H Stainless Steel Pipe. Before cutting, the test piece was heated in 3 1/2 hr to 1350°F, held for 30

min and then allowed to cool slowly in the furnace. The cooling time to 300°F was approximately 2 hrs. Heat treatment to approximate more closely the condition of the loop piping, when it will be cut, was impractical.

Only one die, Die No. 3, was tested. The force applied was 187.5 tons, but the pipe was not severed. Greater force was not available from the press used for testing this die.

The test piece is shown on Fig. I and the test is described further in the discussion 6.4.

3.3. 1 1/2-in., Schedule 80 Stainless Steel Pipe. The results of those tests that were made while the die design was still under development are given in Table II. The test pieces were all 347 stainless steel Commercial Grade.

The results of tests made on a prototype die are given in Table III. However, the test conditions and design varied somewhat from test to test. A detailed record of the testing is given in Table IV. Part of these tests were made on 347 stainless steel, commercial grade, and part were made on 347H stainless steel. The 347H stainless steel had been heated in approximately 5 1/2 hrs to 1350°F, held for 30 min, and then allowed to cool in the furnace. The cooling time to 300°F was 3 hrs.

No difference due to the different materials was observed in the test results.

Table I. Results of Tests on 1/2-in. Outside Diameter x 0.065-in. Wall, 347 Stainless Steel

Test Piece	Fig. No.	Die No.	Pressure (psig)	Flow Rate cm^3 (STP)/sec	Force (tons)	Text Reference
1	2	1	5.0	0.00	8	6.2
1			15.0	3.0×10^{-9}*		
1A			5.0	2.1×10^{-3}		
2	3	2	5.0	2.5×10^{-4}	7	6.3
2A			5.0	6.7×10^{-3}		

*The flow rate thru this test piece half was measured by mass spectrometer. All other flow rates were measured by differential manometer.

4. General Description

In the description and discussion, the test piece of pipe will

always be referred to as if placed horizontally between the die halves with the cutting force being applied downwardly on the top die half. The expression "bend point" shall mean the location on the side of the pipe where the maximum bending stress occurs as the pipe is collapsed and cut. The top wall means the wall on top between the bend points. The bottom wall is defined in a similar way.

All dies tested operate by forcing the walls together during cutting. The dies differ as to the shape of the wall forming blocks, in the type of cut made, and in details to hold the pipe straight. The dies are classified according to the manner of cutting.

Table II. Results of Tests on 1 1/2-in., Schedule-80, Type 347 Stainless Steel Commercial Grade

Flow rates were measured by a Flow Meter calibrated for the 0 to 20 000 cm^3/min range unless otherwise noted

Test Piece	Fig. No.	Die No.	Pressure (psig)	Flow Rate [cm^3 (STP)/sec]	Force (tons)	Text Reference
1	11	7	0.5	3.8×10^{0}*		6.8
1A			0.5	3.0×10^{0}*		
2	12	8	0.5	5.5×10^{1}		6.9
3	13	9	2.0	1.5×10^{-4}**	110	6.10
3A			2.1	4.8×10^{-5}**		
4		11	2.5	2.3×10^{-4}	163	6.12

*Flow rate was measured by a flow meter calibrated for the 0 to 300 cm^3/min range.

**Flow rate was measured by a differential manometer.

Type I. This type shears out a short length of pipe. The walls are sheared during the forming action which seals the top wall to the bottom wall. The shearing punch is on the top die half. Figure 2 shows this type die. The die is open with the punch at the bottom of the photo.

Type II. This type pinches the walls between a blade and an anvil. The walls are severed during the forming action which seals the top wall to the bottom wall. Figure 3 shows this type die. The die is open with the blade at the bottom of the photo.

Table III. Results of Tests on 1 1/2-in., Schedule-80, 347 Stainless Steel Commercial Grade, and 347H Stainless Steel Pipe

Flow Rates were measured by a flow meter calibrated for the 0 to 20 000 cm^3/min range unless otherwise noted

Test Pressure: 0.5 psig
Text Reference: 6.15

Test Piece	Fig. No.	Die No.	Flow Rate cm^3(STP)/sec	Force (tons)	Material
1	17	14	1.7×10^1	75	Comm.
1A			1.7×10^1		
2		14	1.1×10^1	88	Comm.
2A			1.4×10^0*		
3		14	3.3×10^0	88	Comm.
3A			1.0×10^1		
4		14	1.8×10^1	108	Comm.
4A			4.1×10^1		
5		14	5.5×10^1	108	Comm.
5A			7.0×10^1		
6		14	3.0×10^1	150	Comm.
6A			2.2×10^1		
7		14	8.8×10^0	150	H
8	17	14	3.8×10^{-1}*	150	H
8A			1.7×10^1		
9		14	3.1×10^1	160	H
10		14	2.8×10^{-1}	188	H
10A			1.8×10^{-2}		

*Flow Rate was measured by a flow meter calibrated for the 0 to 300 cm^3/min range.

Table IV. Details of Tests on 1 1/2-in. Schedule-80, Stainless Steel Pipe

Test Piece No.	Material	Cutting Force in 1000 lb	Qualifying Conditions	Remarks
1	347 stainless steel commercial	150	Molybdenum disulphide powder was applied by dipping a brush in a bucket and brushing on the male die	The pipe was completely severed. It snapped apart. A foreign body trapped in the die made a dent on one piece of the female side
2	347 stainless steel commercial	175	No additional lubrication applied	Some sticking of metal to die was noted
3	347 stainless steel commercial	172	Before this cut was made three shallow grooves were ground in the face of the forming blocks to increase the drag on them to prevent pull out	The pull out had been reduced somewhat
4	347 stainless steel commercial	215	The forming blocks were spaced outward 0.062 in.	The leak rate or pull out was not altered significantly
5	347 stainless steel commercial	215	The entire face of the forming blocks was coarse ground	The part did not snap apart completely but eased apart and was easily pulled apart by hand. The dies have not increased in galling for the last two cuts and are not bad

Table IV (continued)

Test Piece No.	Material	Cutting Force in 1000 lb	Qualifying Conditions	Remarks
6	347 stainless steel commercial		The forming blocks now had 1/16 in. out and 1/32 in. up spacing	The load was taken to 125 tons and the sample removed for inspection. It was not fractured. The load was increased to 150 tons but the part did not fracture. The part was broken by hand pounding. It was thought that the pull out which still existed was caused by a too sharp blade. Accordingly, 0.013 in. was removed from the blade and dulled by this much
7	347H stainless steel	300	0.062 out spacing forming blocks	Did not cut completely. Better seal. Less pull out
8	347H stainless steel	6000	1/16 in. out spacing of forming blocks and 0.013 in. paper shim under blade. Straightening block was in place on one side	Did not shear completely. Broke by hand. Bigger radius indicated on blade. It appears that lubrication is not required. Final die design released for fabrication with the forming blocks made with rough surfaces and spaced out 1/16 in. The straightening block had little effect.

Table IV (continued)

Test Piece No.	Material	Cutting Force in 1000 lb	Qualifying Conditions	Remarks
9	347H Stainless Steel	6200	1/16 in. out spacing of forming blocks. Pipe was lubricated by moly disulfide powder	0.0135 was removed from shoulders of male die holder and grooves in forming blocks were cut more deeply. This resulted in the forming blocks being 0.0135 higher with relation to the die. Part was severed to the point that it was broken apart by simple hand force. Straightening block was on one side. Pull out was all on the opposite side and was increased over 8. Note: Each forming block had moved out approximately 1/16 in. during the cut.
10	347H stainless steel		1/16 in. out on forming blocks. Dowel pins in forming blocks. Groove depth increased to 1/32 in. in forming block	All lubricant was carefully removed from dies. Pipe was not lubricated. Load was taken to 189 tons and approximately 1/16 in. wall remained. The part was then lubricated with moly disulfide and the load was then taken to 153 tons. The part was broken by hand with no blows. A slight pullout was observed and small water leaks showed at pull out points.

5. General Discussion

Experience shows that a straight bladed pinch cut on pipe or tubing springs open a small amount. The thought occurred to the writer that it might be possible to form the pipe during cutting so that springback would hold the cut ends closed. With this thought in mind three concepts evolved.

The first concept may be termed the oil can principle. The bottom of an ordinary oil squirt can has a curvature which will resist being pushed in. If pushed in to force oil through the spout, it will return to the original out position when released. It was thought that a pinch cut end as shown in Fig. 4 could be made to close more tightly by reversing the curvature of surfaces A. It was thought that stresses similar to those in an oil can would result and would offset some of the stresses in the walls tending to cause opening springback.

The second concept may be termed the differential springback principle. If the top wall were forced against the bottom wall and at the same time its direction of curvature were reversed, it would springback to assume a longer radius of curvature, the springback in it would cause the bottom wall to follow the top wall and only the difference between the two springbacks would be effective in opening the edges of the walls.

The third concept may be termed the arc length difference principle. The idea was to flatten the pipe so that the top wall would be the same width as the bottom wall, and then bend the two walls into a circular arc shape. This would cause large tensile stresses in the bottom wall and correspondingly large compression of the top wall. The tensile and compression stresses would cause springback which would hold the two walls together. Type II dies may utilize this concept.

For a Type II die, if bending stresses are neglected and it is assumed that the top and bottom wall widths are equal, the radius of the anvil against which the pipe is cut can be calculated by the following formula:

$$R = T \left(\frac{1 + 2e}{2e} \right)$$

Where R = Radius of the anvil in inches

T = Wall thickness of pipe in inches

e = Decimal fractional increase in width of the bottom wall.

The ideal radius of the anvil would be that radius which would cause the bottom wall of the pipe to be in maximum transverse tension after the cut is made, and would be accompanied by a large e. In determining the ideal radius, bending and shear stresses would have to be considered and the problem is beyond the scope of this work. A value for e of 0.032 was used on the die which gave the best results. This value of e was chosen with the thought in mind that the metal of the bottom wall should be elongated well above the yield point in the transverse direction. Since the best value of e was not known an estimate was made.

The first concept was tested by making a straight pinch cut and then deforming it to the reversed curvature position of Fig. 4. Springback was reduced. The second concept was tested by forcing a simple rounded end punch into the side of 1/2-in. o.d. x 0.065-in. wall tubing placed inside another tube having an inside diameter of 17/32-in. The top wall was forced against the bottom wall and the test piece was then sawed into two pieces. The walls remained tightly together but a longitudinal fracture had occurred in the top wall near one bend point. The punch and test piece are shown in Fig. 5. The third concept was tested by cutting a short length of pipe, flattening and then bending it as shown in Fig. 6. The bottom wall fractured due to tension.

With a Type I die design in mind, a stepped punch was made to learn if the sharp corner of the punch would cause transverse fracture of the top wall. Transverse fracture did not occur, but longitudinal fracture did occur as shown on Fig. 7.

6. Detail Discussion

In the balance of the discussion, the material is arranged in the order in which the work was done. Each die is designated by a number, and this number is given at the beginning of discussion concerning the die. Table V lists the die numbers and related information, and will serve as a cross index for this report.

6.1. Die No. 1. This was a Type I die for 1/2-in. o.d. x 0.065-in. wall tube. It used the oil can and differential springback principles. It shaped the cut ends into a 70° included angle vee. The point of the vee was rounded to a radius equal to the outside diameter of the tube. The flared vee shape was intended to prevent longitudinal fracture of the top wall. It did not shear out a section of pipe because the shearing punch was too short. The test piece was sawed into two pieces and leak tested. The results are given in Table I, Test Piece I. Die and test piece are on Fig. 2. No further work was done on this type die because Type II held promise of simpler operation.

6.2. Die No. 2. This die was for use on 1/2-in. o.d. x 0.065 wall tube. It was the first Type II die made and was based on oil can and differential springback principles. The blade had about a 0.010-in. radius on the cutting edge and was on the top die half between two forming shoulders. The purpose of the 0.010-in. radius was to force the top wall against the bottom wall and effect a seal before the top wall was cut. The purpose of the forming shoulders was to force the top wall into a reverse curve against the bottom wall and to produce as much oil can effect as possible. They also were to prevent piercing of the top wall by the knife. The anvil was vee shaped with the point of the vee rounded to fit the outside diameter of the tube. The included angle of the vee was 76°. The shapes of the severed ends indicate the top wall was pierced before the seal was complete. The results are given in Table I, Test Piece 2. Die and test piece are on Fig. 3.

6.3. Die No. 3. A Type II die was made for 2 1/2-in. schedule 160, 347H stainless steel pipe. It was based on the same principles as Die

No. 2. The test piece is shown in Fig. 1, and the results are in 3.2 of this report.

As a simple easy test, a piece of 2-in. schedule 80, 347 stainless steel pipe was cut in this die. The severed ends showed no fracture and very little springback.

6.4. Die No. 4. As the requirements of the No. 2 Loop had changed to 1 1/2-in. schedule 80, 347H stainless steel pipe, Die No. 4 was made to meet this requirement. It was based on the same principles as Die No. 3, but differed from past dies in that an arc of a circle with radius larger than the radius of the outside diameter of the pipe was used instead of a vee with the bottom rounded. Punches were located on the top die half on each side of the knife so that they would partially shear the top wall in a vertical plane passing thru the inner surface bend points. The purpose of the punches was to force the top wall against the bottom wall and create closing springback and avoid longitudinal rupture of the top wall. This die is shown with the anvil as modified in Fig. 8. The modification was made to cause more deformation of the bottom wall and thus prevent fracture of the top wall. It was only partially successful.

6.5. Die No. 5. This was another Type II die made on the same principles as die No. 4. It had the rounded end vee design, but the included angle of the vee was 90° rather than 76°. Punches locally forced the top wall against the bottom wall just above the inner surface bend points. The purpose of the punches was to force the top wall tightly against the bottom wall so that opening springback would not occur, and at the same time prevent transverse stress in the top wall. This die was made with removable knife, forming blocks, and anvil so that modifications could be easily made. The test piece at the bottom of Fig. 9 is shown resting on the anvil insert. The knife pierced the top wall long before the walls were together and a slight longitudinal fracture occurred indicating that further height on the forming blocks would cause this type fracture to be extreme. As an experiment, the punches and blade were removed and the forming blocks were forced into the pipe to determine if longitudinal fracture would occur. It did occur as shown by the test piece.

All dies discussed in this report after this point, except numbers 15 and 16, were made using the punch holder and die holder of Die No. 5.

6.6. Die No. 6. Using Die No. 5 holders, another Type II die was made. A new set of forming blocks were made which would not push the top wall down so far at the shoulders. An insert was also made to replace the blade. The blocks, blade insert, anvil and test piece are shown on Fig. 10. The two flat blocks are only spacers to hold the forming blocks relative to the blade insert while the picture was taken. It may be seen that the ends of the vee on each side of the test piece have been flattened slightly by the action of the forming blocks and insert. The purpose of the flattening was to force the bend points further down so that more of the top wall would be inside the vee and thus prevent longitudinal fracture. It did not work because the bend points were too well

formed when the flattening occurred. It was concluded that it is impractical to shift the bend points once they are well started.

6.7. Die No. 7. This Type II die was made to form the severed ends into an arc of a circle. The radius of the anvil was 3 7/16-in. It was thought the large radius would cause the bend points to be nearly diametrically opposite and longitudinal fracture would be eliminated. The forming blocks were made to form a groove in the top wall on each side of the blade during the cutting process. It was believed this would give a better seal. Test piece ends and the anvil insert are shown on Fig. 11. The test piece was not completely severed and was broken by pounding. All fracture had been eliminated but something was left to be desired in leak rate. There was doubt as to the validity of the leak rate because of the incomplete cut.

6.8. Die No. 8. This Type II die was made with a longer anvil with the idea that it would give a lower leak rate. The radius of the anvil was 3 5/16-in. A new knife was made to match. The test pieces cut with it were not completely severed so a 1/2-in. wide x 0.062-in. thick hardened steel insert was taped to the anvil. A test piece half, anvil, and insert are shown on Fig. 12. Very little groove was made by the forming blocks and the leak rate was about ten times greater than before.

6.9. Die No. 9. This die was made as a Type II and was based on the oil can and arc length difference principles. In order to most effectively use the last principle, the pipe had to be flattened completely before it was bent into an arc. This called for a two stage die that flattened in the first stage, and cut and bent in the second. The second stage die parts were the same as used in Die No. 8, except that the hardened steel insert on the anvil was 0.093-in thick. The first stage used the Die No. 8 knife and forming blocks, but another anvil was made. This anvil is shown on Fig. 13. Force was applied to flatten the pipe until the pipe was completely closed at the center but still open at the bends on each side. The second stage formed the arcs and severed the test piece. The leak rates of the severed ends were the smallest yet obtained by any 1 1/2-in. die.

6.10. Die No. 10. This die was a Type II single stage, but was shaped to use the oil can and arc length difference principles. The anvil was shaped in such a manner that the pipe was almost flattened before it started bending into an arc. The cutting force required to produce a test piece with satisfactory leak rate was found to be too high, and die modifications were made as shown in Fig. 15. Fig. 14 shows the modified die and test piece.

6.11. Die No. 11. This was Die No. 10 after the first modification of the forming blocks (Fig. 15, First Mod.). The modification was done because the cutting force using Die No. 10 had been undesirably high. Die No. 11 gave a leak rate satisfactory for use on No. 2. Loop.

6.12. Die No. 12. This was die No. 10 after the second modification of the forming blocks (Fig. 15, Second Mod.). The modification was made in order to reduce cutting force. Die No. 12 gave an unsatisfactory leak rate.

Table V. Cross Index for Dies Tested

Die No.	Fig. No.	Test Piece	Text Ref.	Drawing Number
1	2	1, Table I	6.2	CSK-EEW-2390, 2422
2	3	2, Table I	6.3	
3	1		6.4	C-EEW-2427, 2428, 2429
4	8		6.5	C-SK-EEW-2462, 2463
5	9		6.6	EEW, Date 4/29/61, Sheets 1 thru 4
6	10		6.7	
7	11	1, Table II	6.8	
8	12	2, Table II	6.9	
9	13	3, Table II	6.10	
10	14, 15		6.11	
11	15	4, Table II	6.12	
12	15		6.13	
13			6.14	D-SK-EEW-2499 & 2500
14	16	Table III	6.15	EEW- Date 6/19/61
15	18		6.17	
16	19		6.17	EEW- Date 3/22/61

6.13. Die No. 13. This die is the one which will be used on No. 2 Loop. It was patterned after Die No. 11. It differs from No. 11 in the shape and length of the anvil. The pocket of the anvil of No. 11 was generated on a grinding wheel by hand operation. The pocket of No. 13 was made by standard lathe operations. The two pockets are very close to the same. The length of the anvil along the pipe axis is shorter on No. 13. This die has not been tested.

6.14. Die No. 14. This die was made to be, as nearly as practical, like Die No. 13 and used the holders and blade of Die No. 11. New forming

blocks were made exactly like those of Die No. 13 except that the forming surface finish was not so rough. The anvil was the one used on Die No. 10, 11, and 12, but was modified as shown on Fig. 15. This was the prototype die referred to in 3.3 of this report.

This die was built to test the correctness of the design of Die No. 13. The results indicate that No. 13 will be satisfactory.

Die No. 14 was varied during testing and an individual discussion of each test is given in Table IV.

The particular arrangement of Die No. 14 which cut Test Piece No. 8 is shown in Fig. 16. However, no dowel pins were in the forming blocks during this cut. Half of test pieces 1 and 8 are shown on Fig. 17. This photo illustrates the effect of a 1/16-in. difference in longitudinal position of the forming blocks and the effect of transverse roughening and grooving of these blocks. If the die parts are too smoothly finished, the top wall of the pipe near the bottom surface tends to pull out or fracture as shown by Test Piece 1 and this causes a high leak rate. Roughening of the forming blocks tends to prevent the test piece half from moving longitudinally in the die and reduces pull out as shown by Test Piece 8.

6.15. Die No's 15 and 16. These dies are shown on Fig. 18 and 19 respectively. They are both Type II dies for 1/2-in o.d. x 0.065 wall tube. However, the blade on these dies was made in an arc shape and fit over the anvil instead of into the anvil as on other Type II dies. The test pieces had a high leak rate and the design was abondoned.

Unclassified
Photo 37145

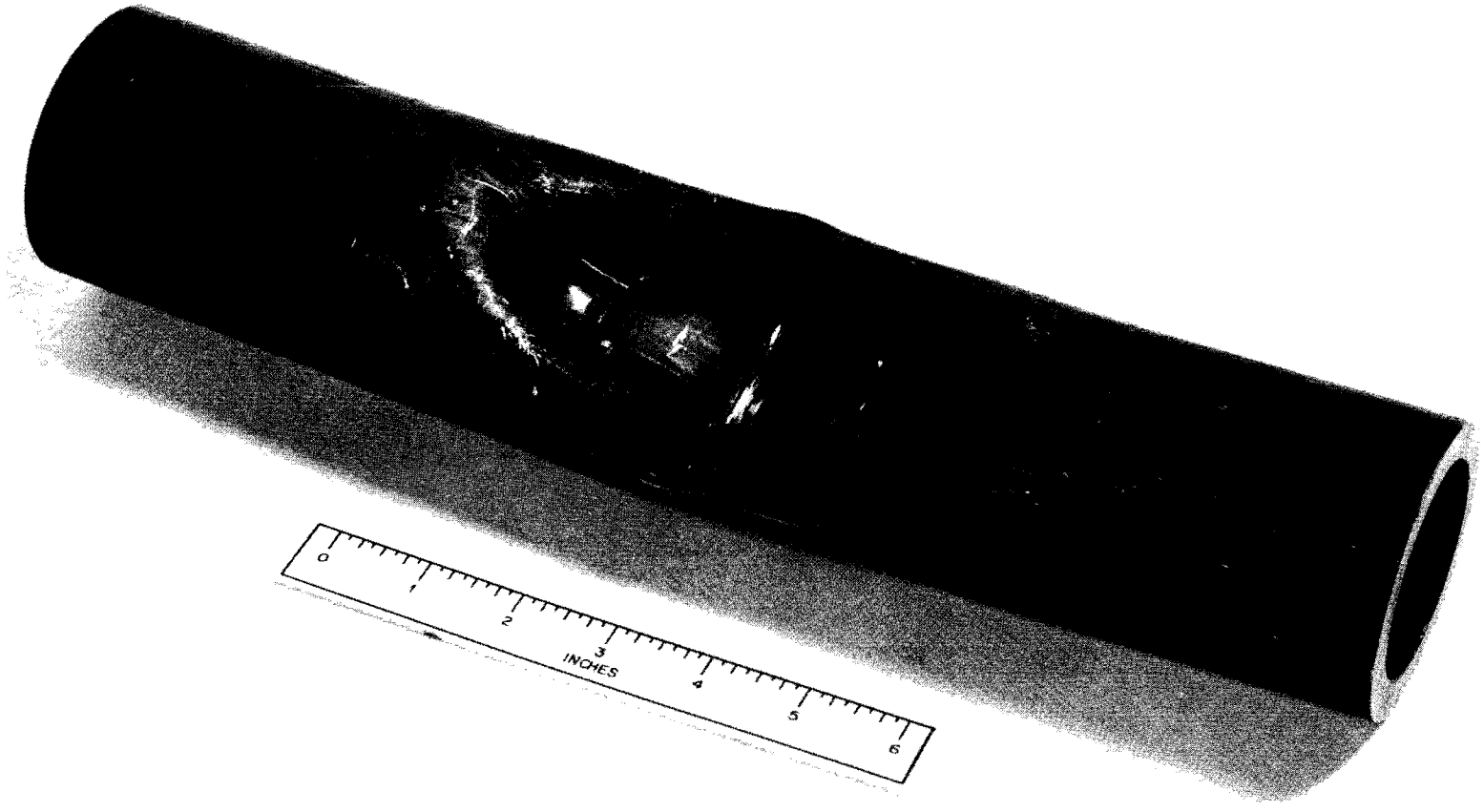

Fig. 1. Incompletely Severed 2 1/2-in. Schedule-160 Pipe.

Unclassified
Photo 37146

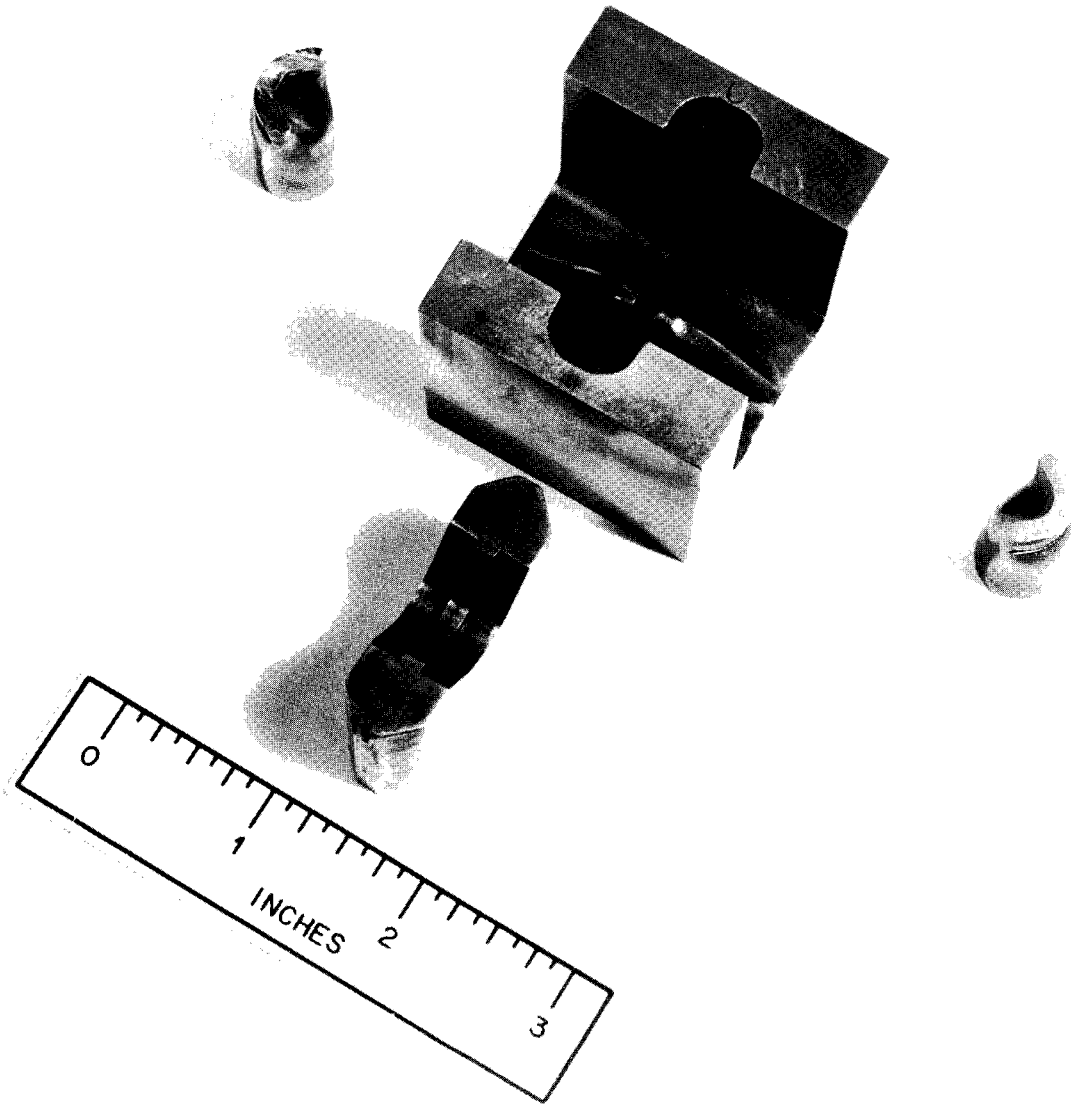

Fig. 2. Type I — Shear Die.

Unclassified
Photo 37141

Fig. 3. Type II — Pinch Die.

Unclassified
ORNL LR DWG 63744

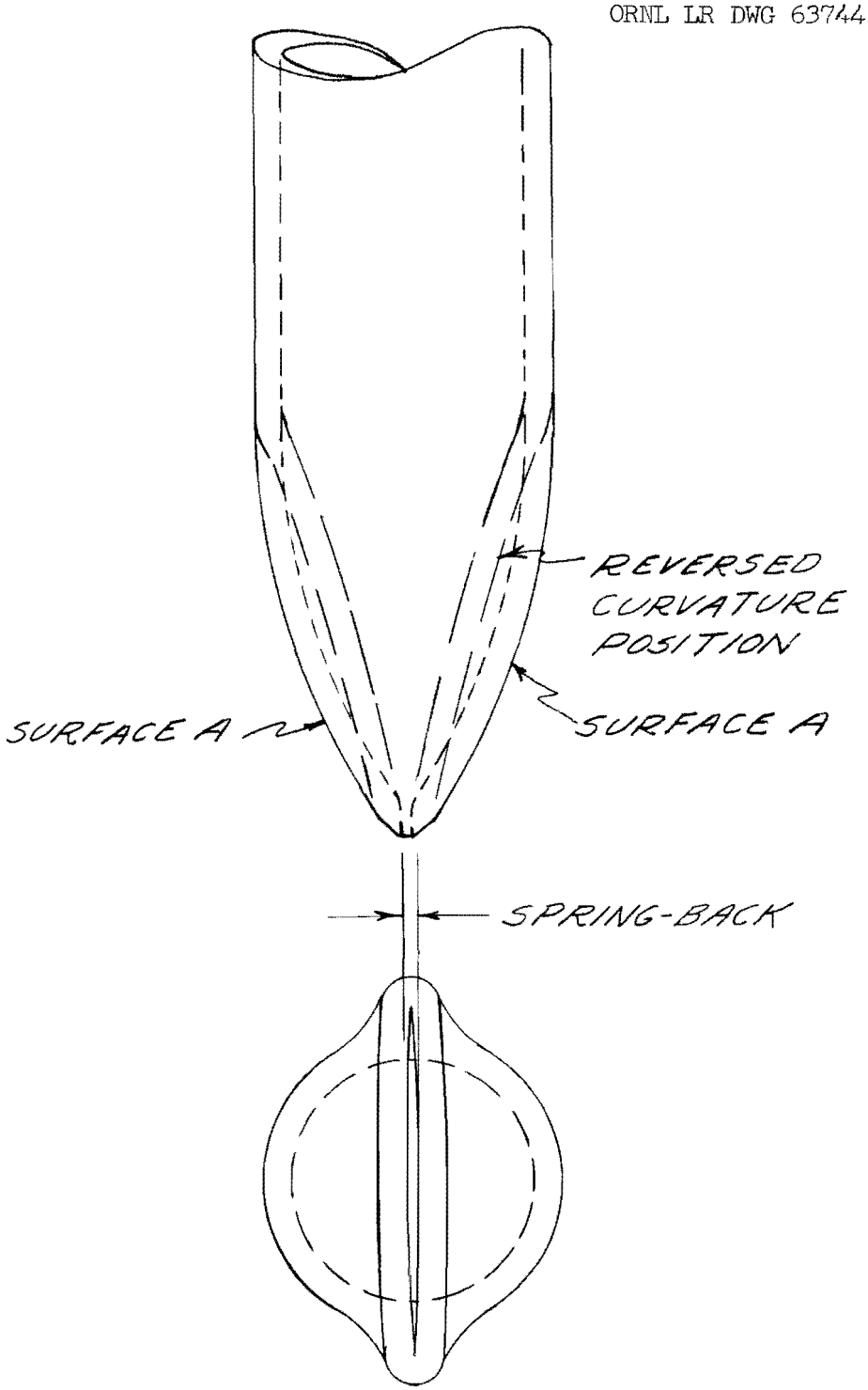

Fig. 4. Oil Can Principle Applied to Seal Pipe.

Unclassified
Photo 37148

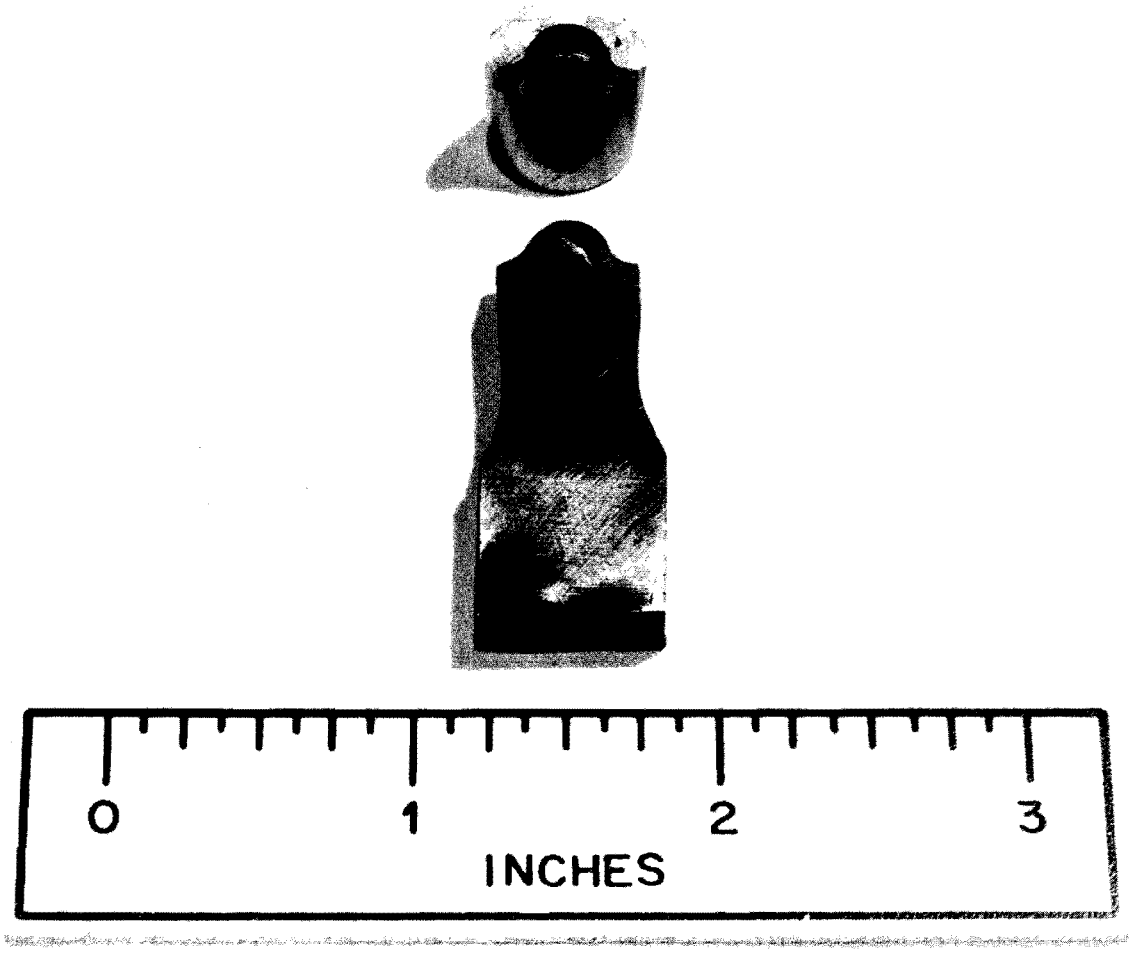

Fig. 5. Forming Die, 1/2-in. o.d.

Unclassified
Photo 37152

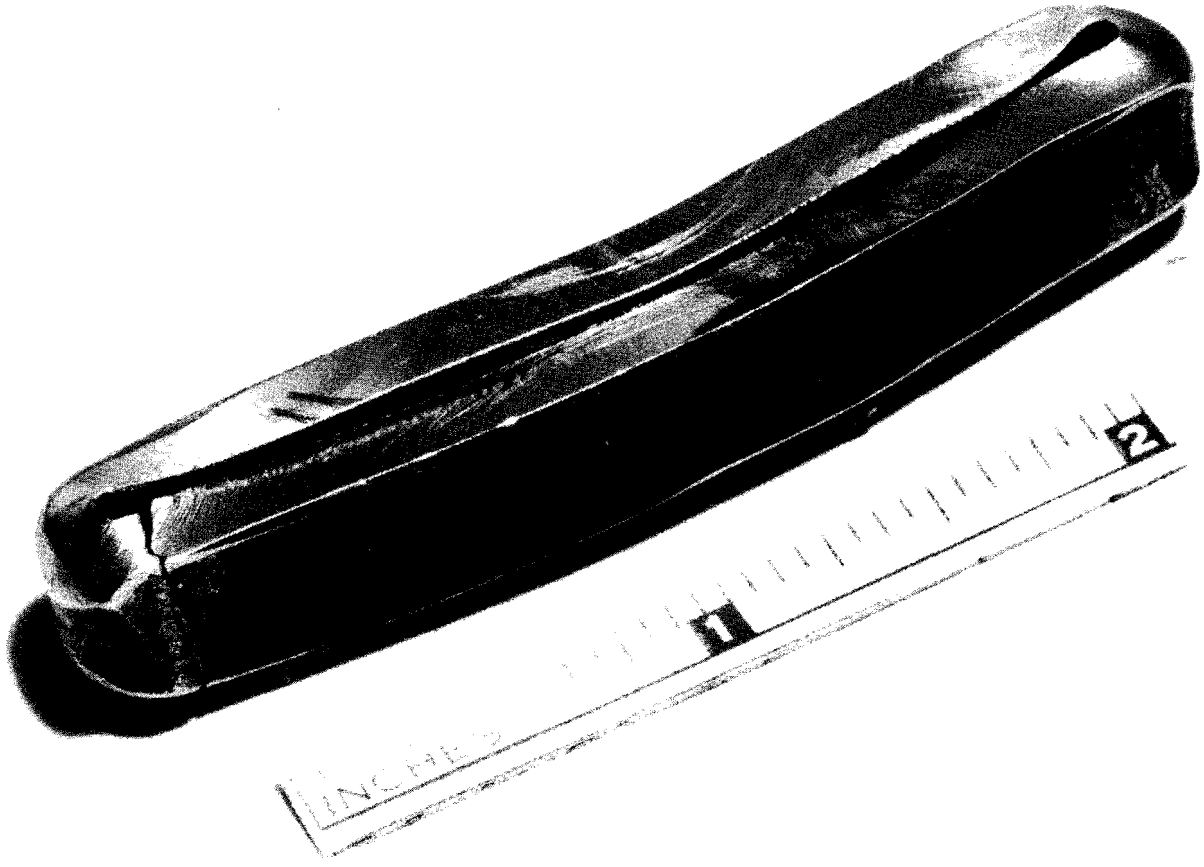

Fig. 6. Flattened and Bent Specimen.

Unclassified
Photo 37150

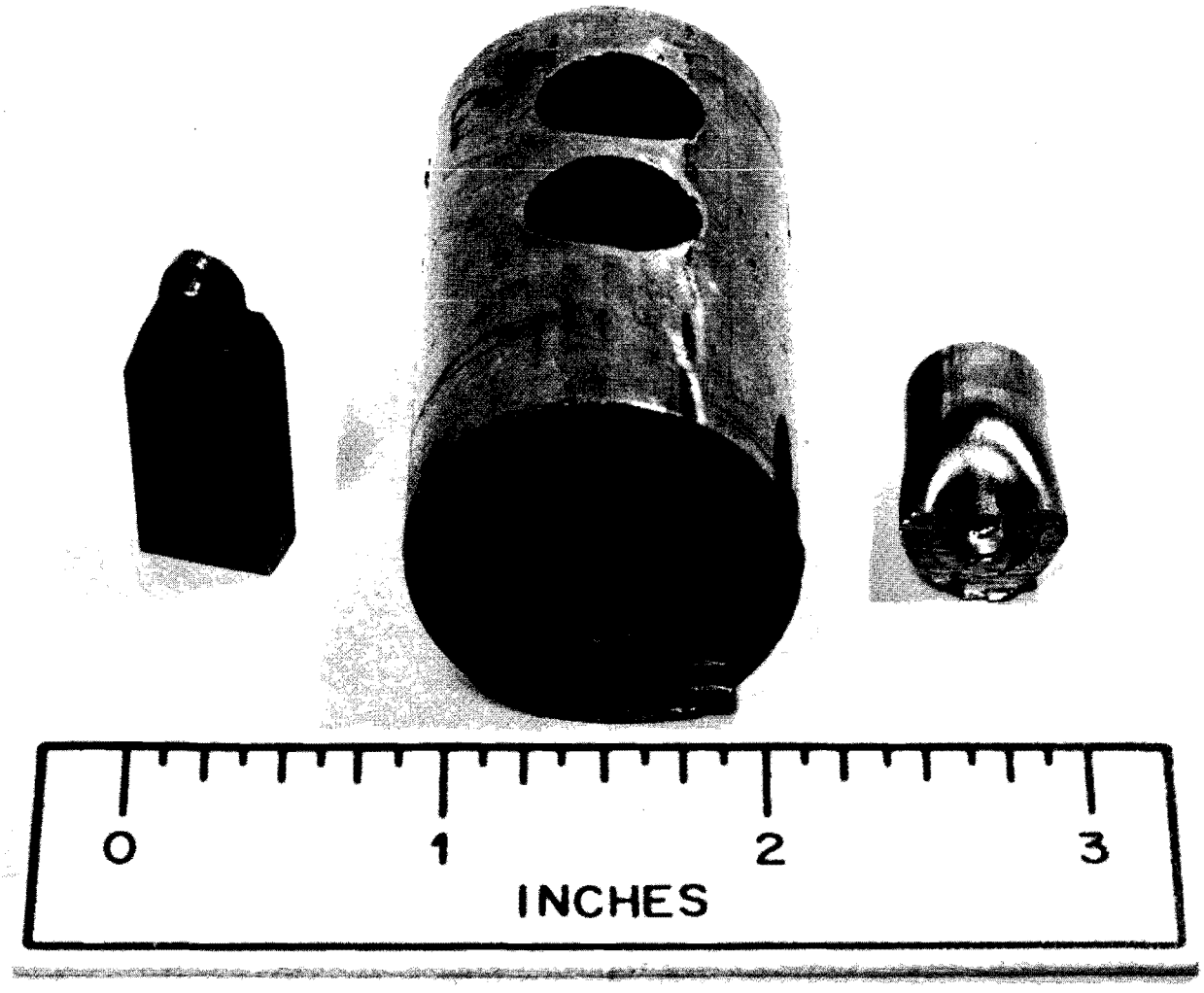

Fig. 7. Stepped Punch Die.

Unclassified
Photo 37140

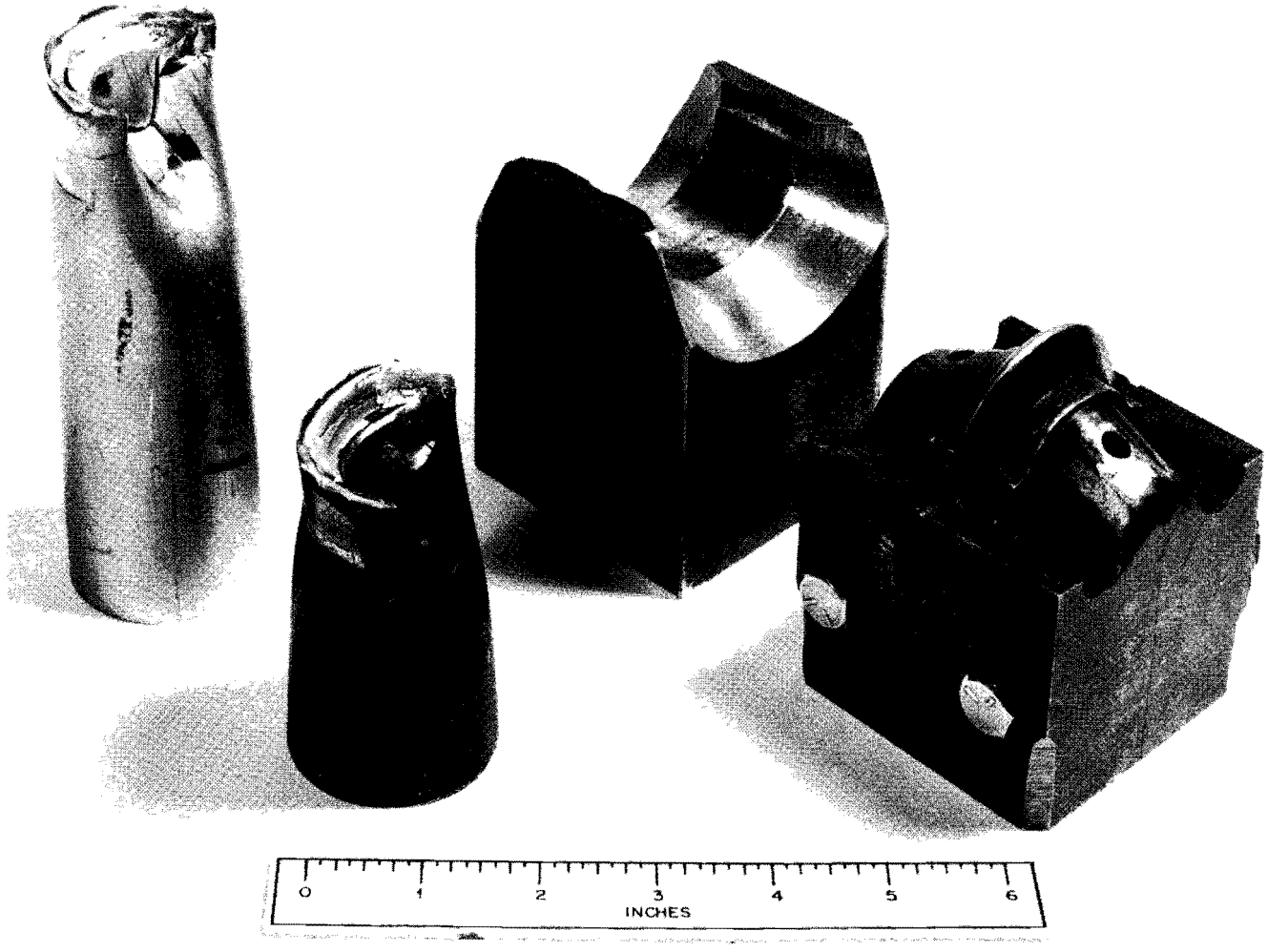

Fig. 8. Die No. 4.

Unclassified
Photo 37147

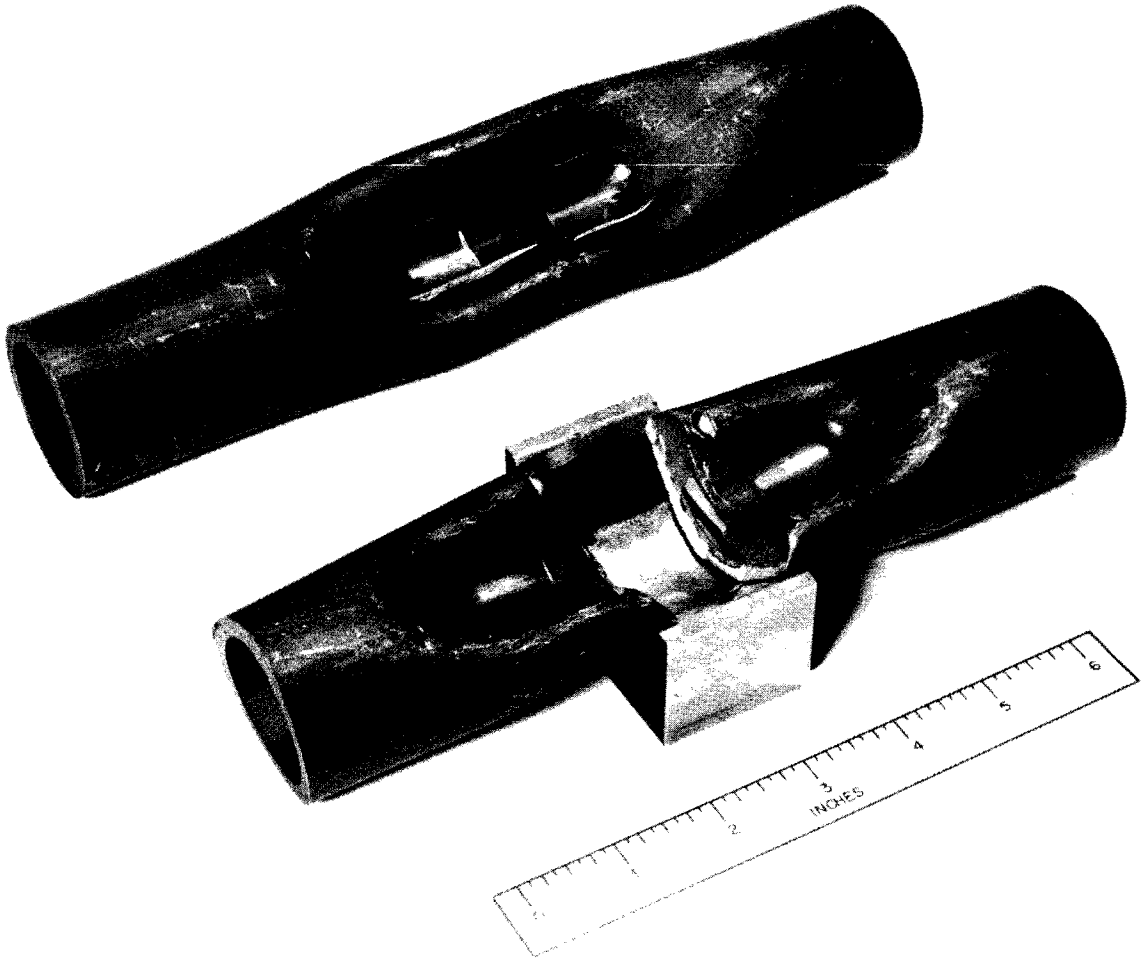

Fig. 9. Test Pieces Made with Die No. 5.

Unclassified
Photo 37143

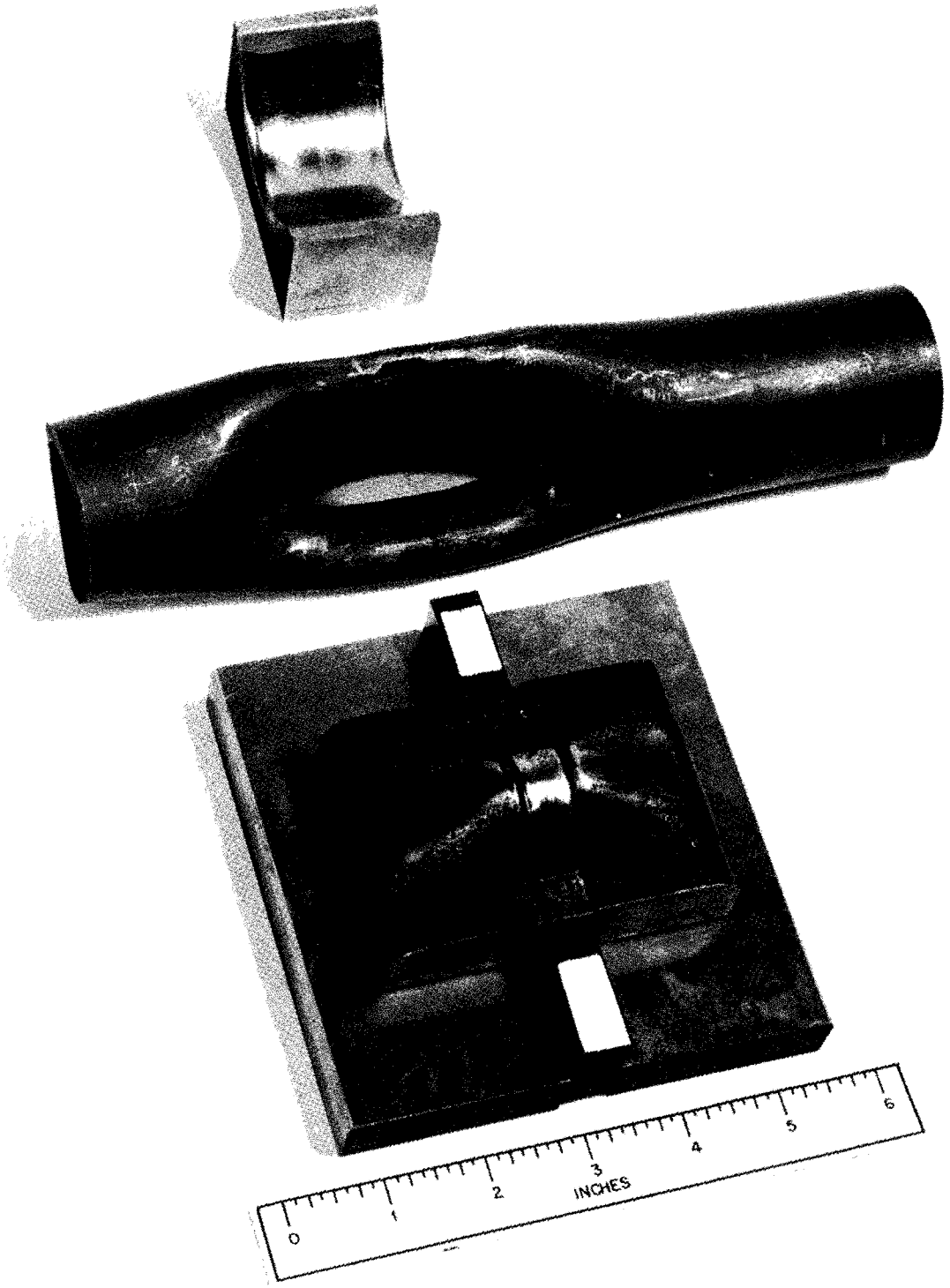

Fig. 10. Die No. 6.

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Photo 37144

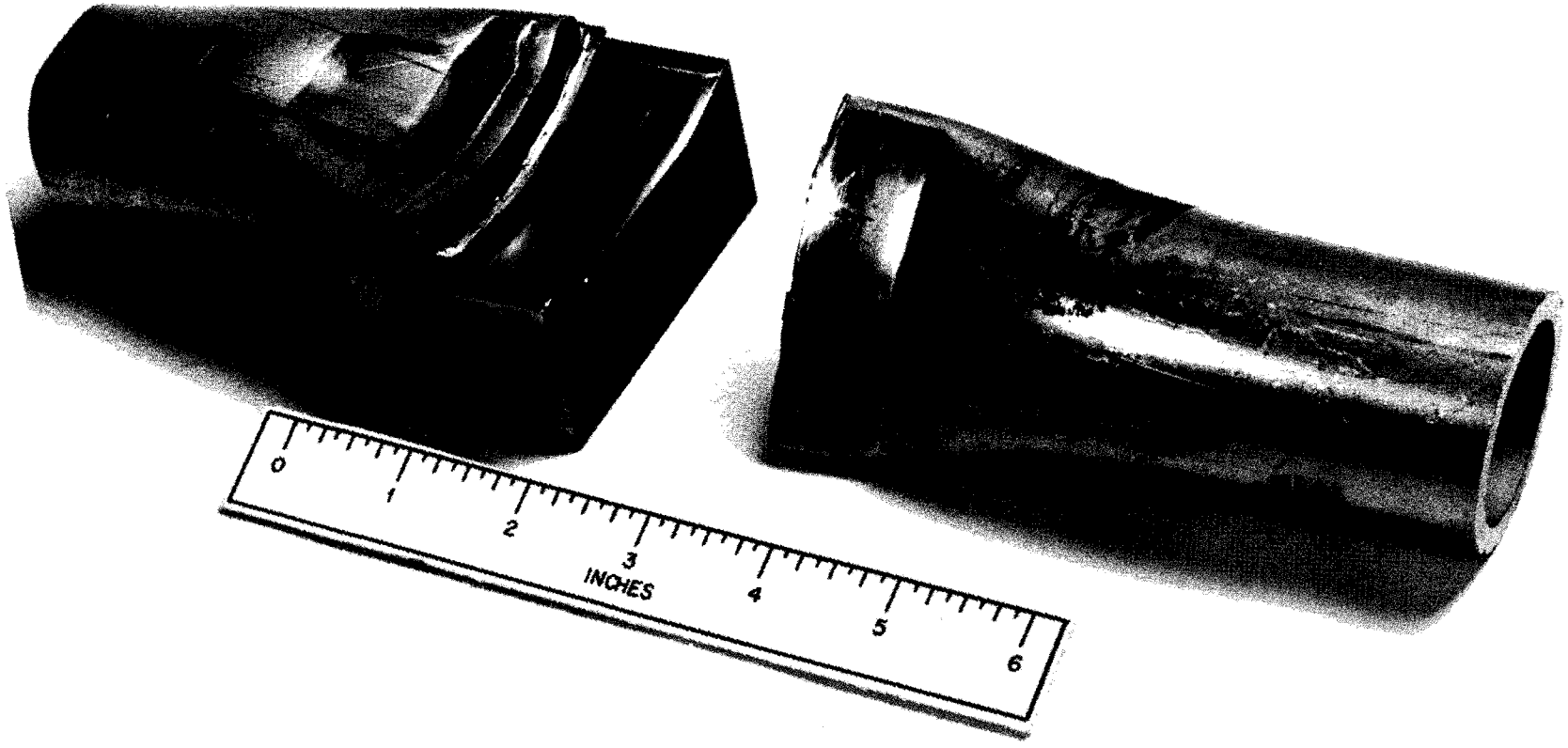

Fig. 11. Pipe Cut Using Die No. 7.

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Photo 37142

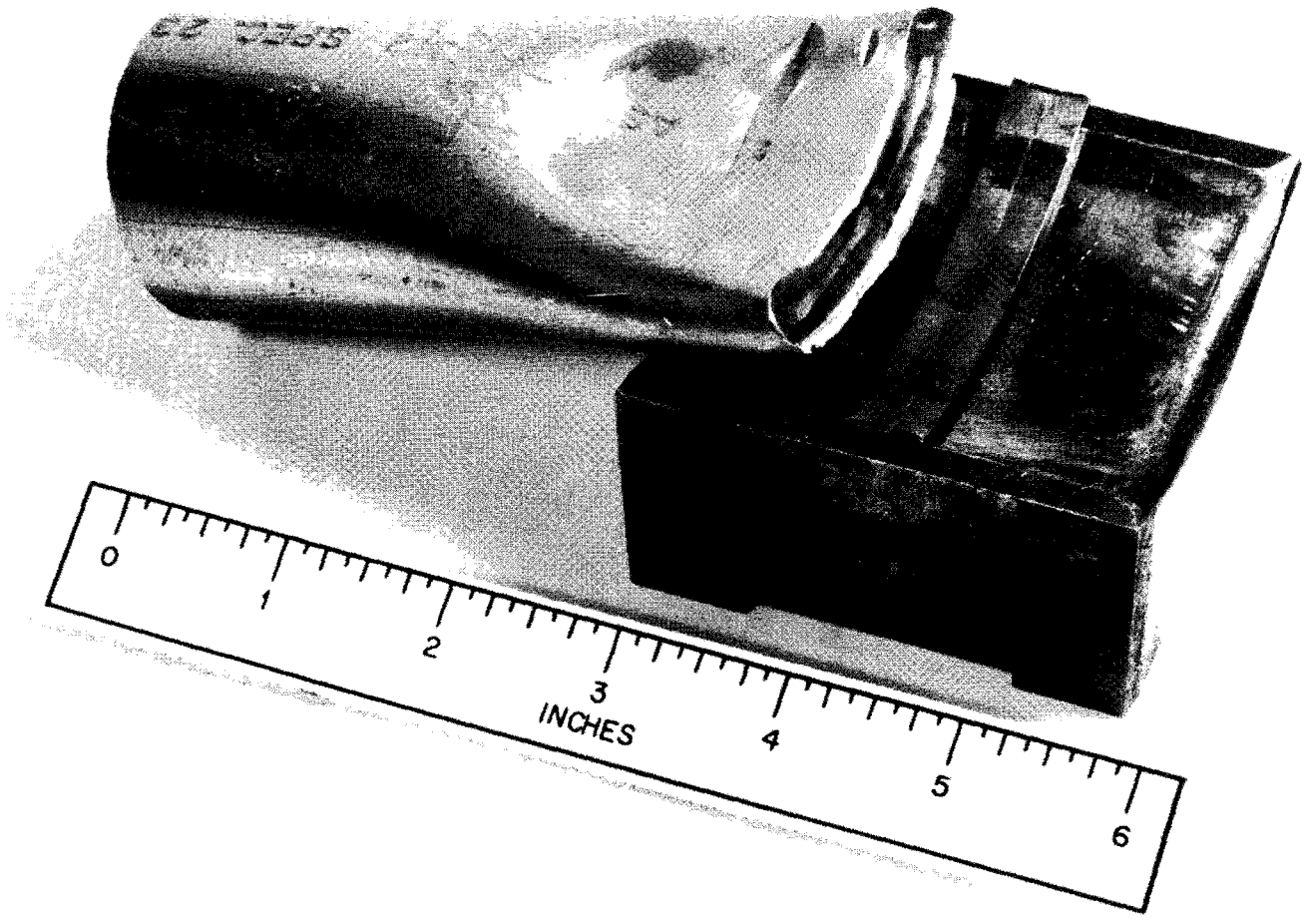

Fig. 12. Pipe Cut Using Die No. 8.

Unclassified
Photo 37156

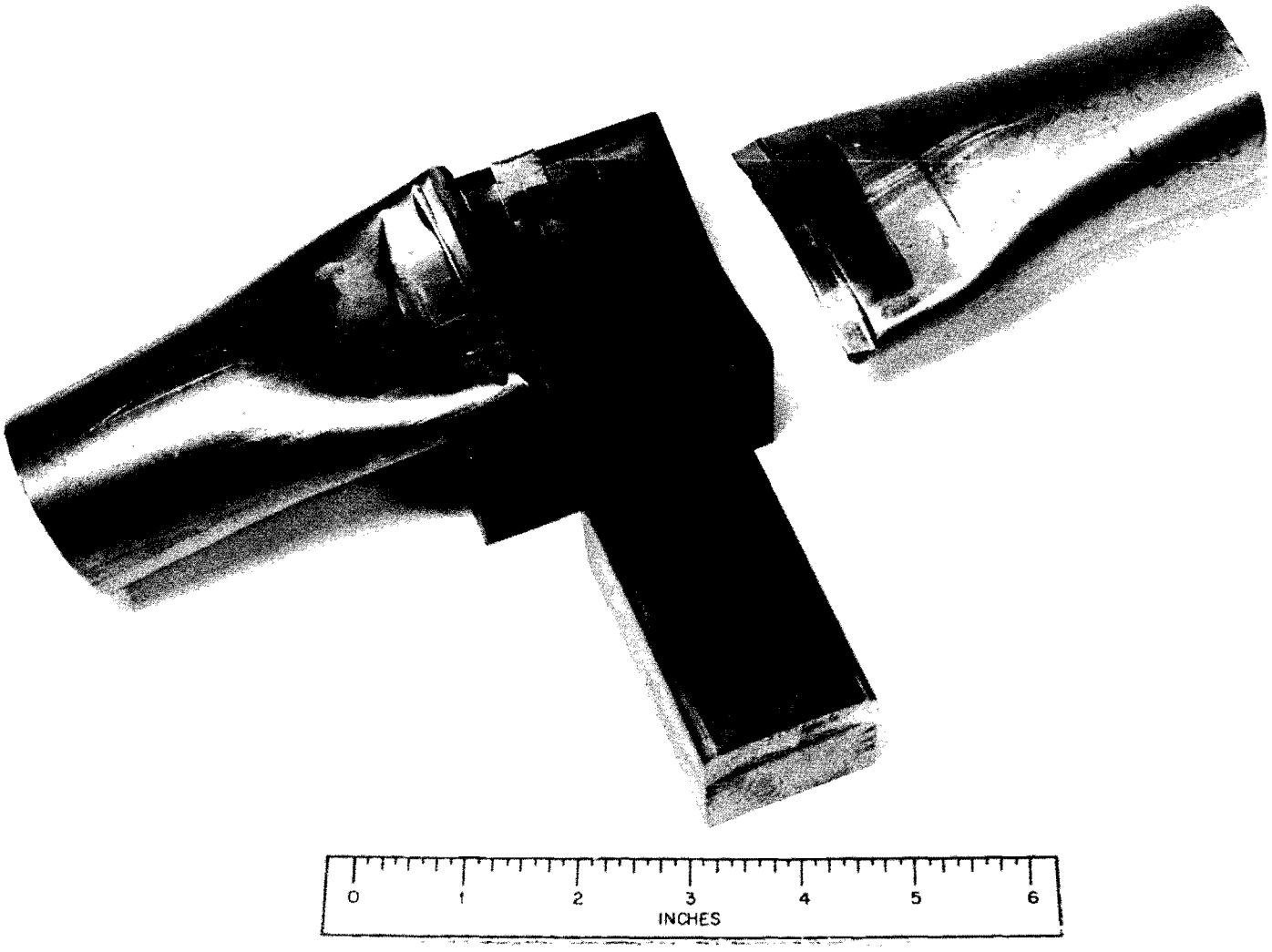

Fig. 13. Die No. 9.

Unclassified
Photo 37154

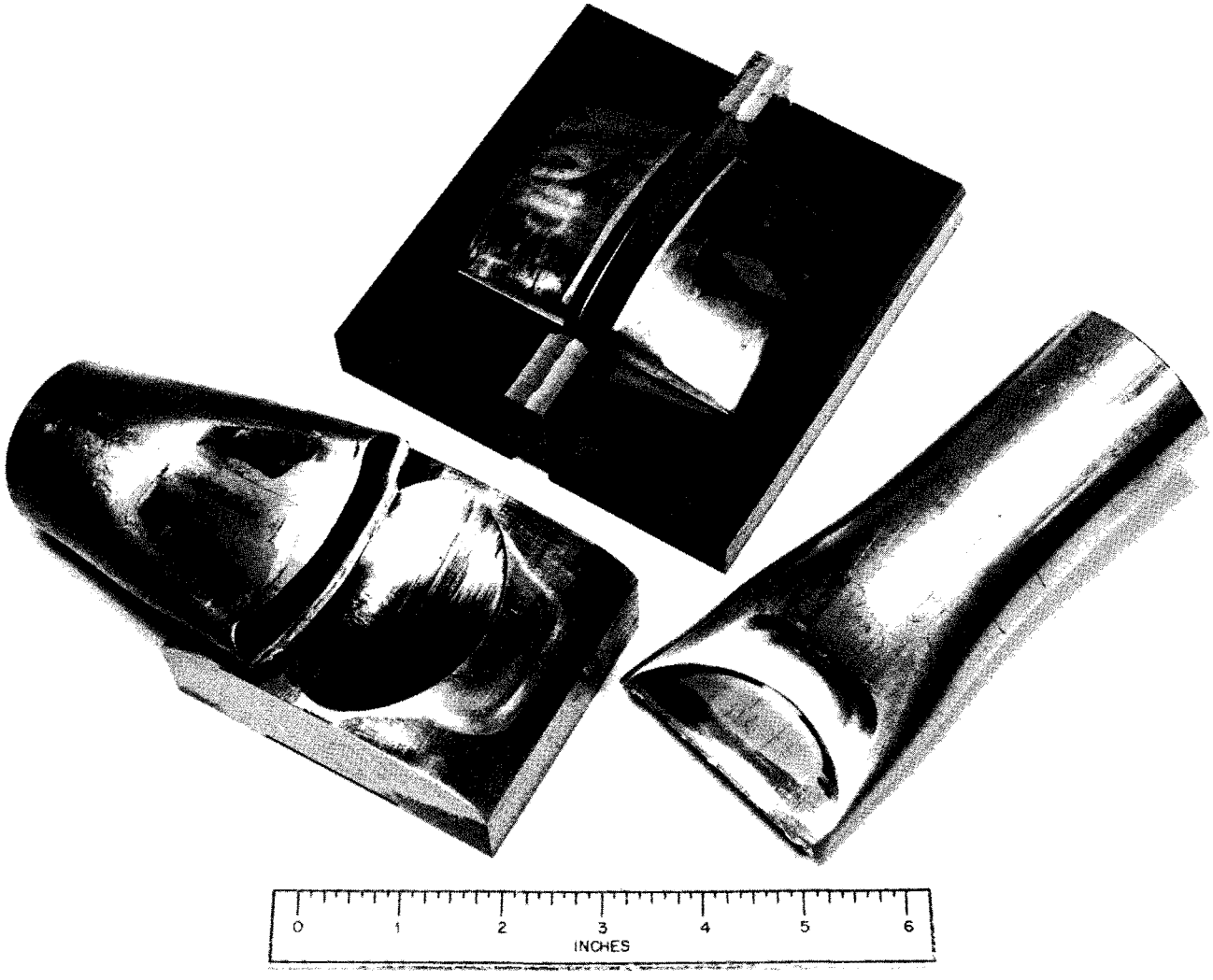

Fig. 14. Die No. 10.

Unclassified
Photo 37153

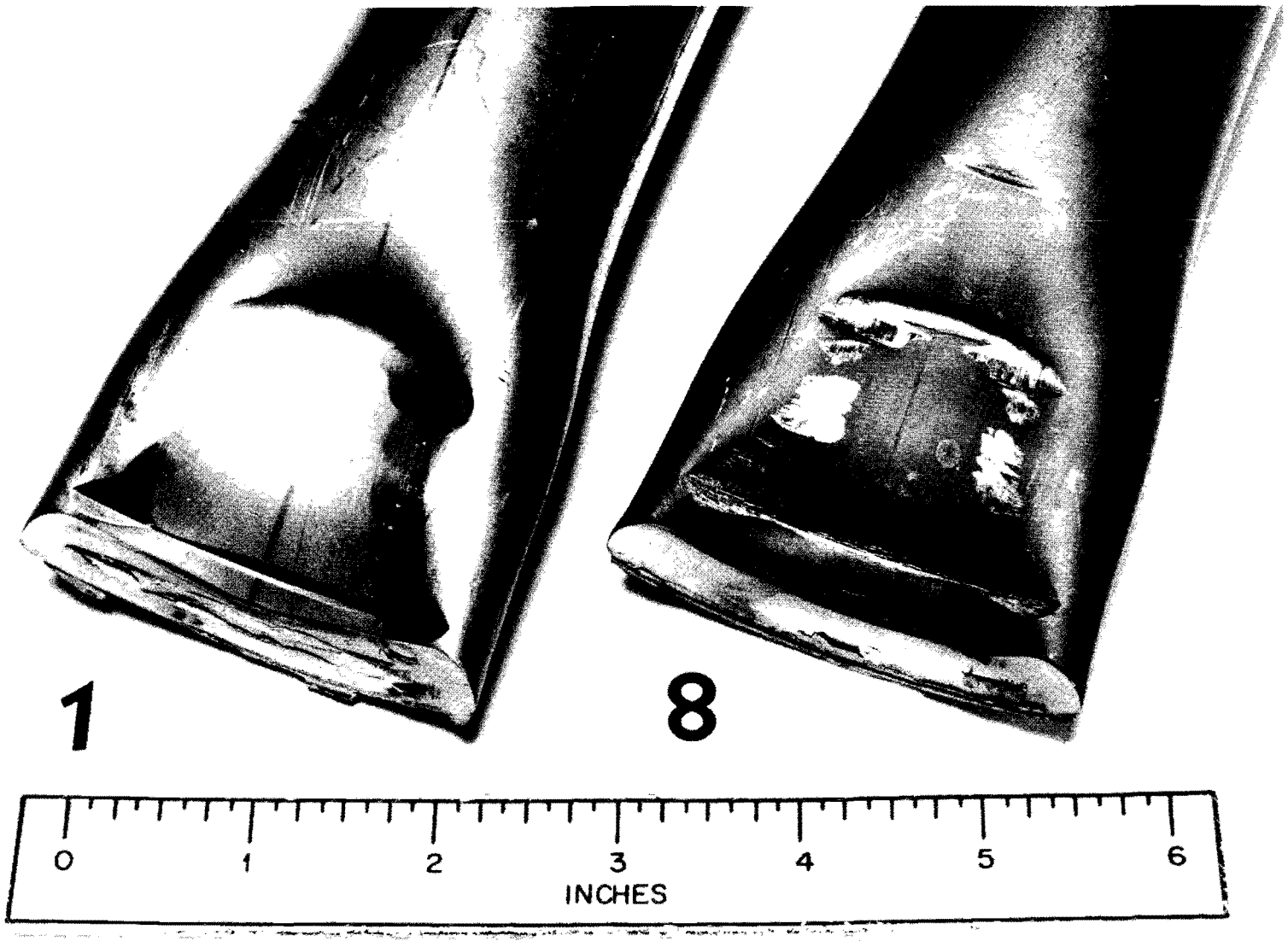

Fig. 17. Test Pieces 1 and 8, Cut on Die No. 14.

Unclassified
Photo 37149

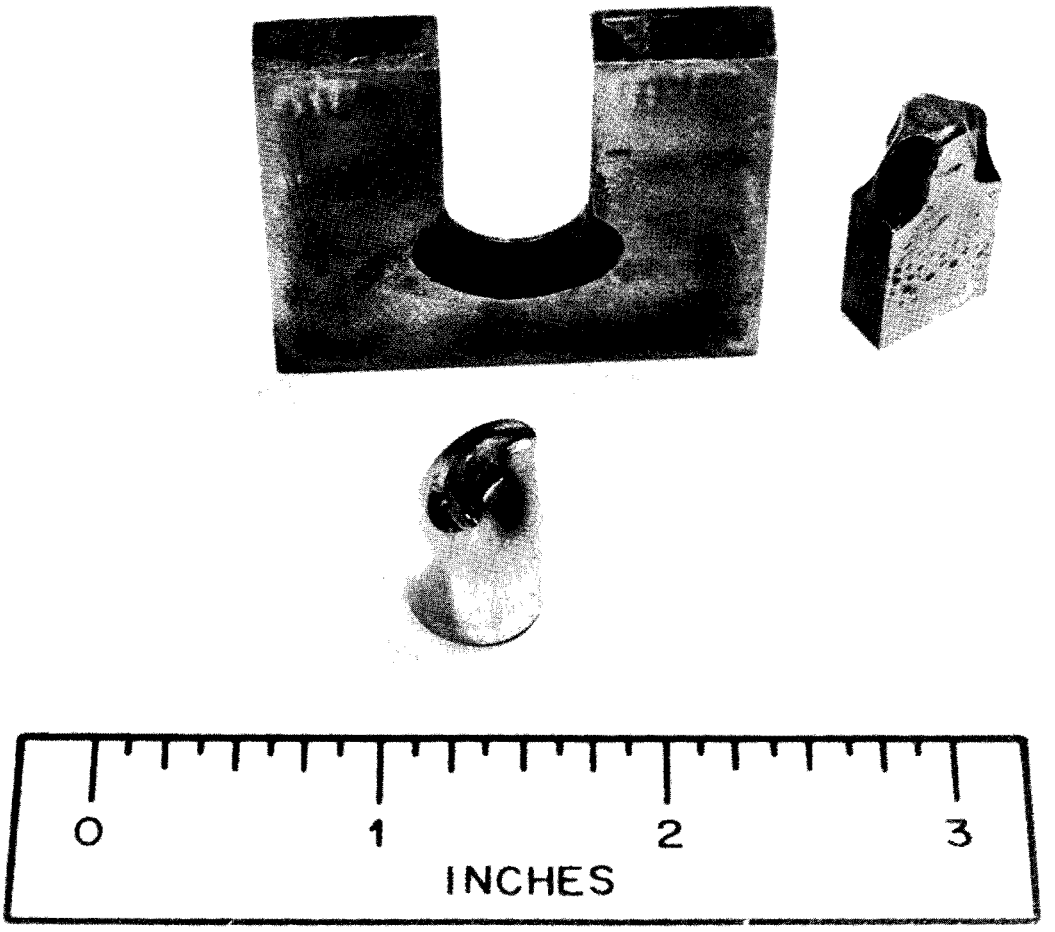

Fig. 18. Die No. 15.

Unclassified
Photo 37151

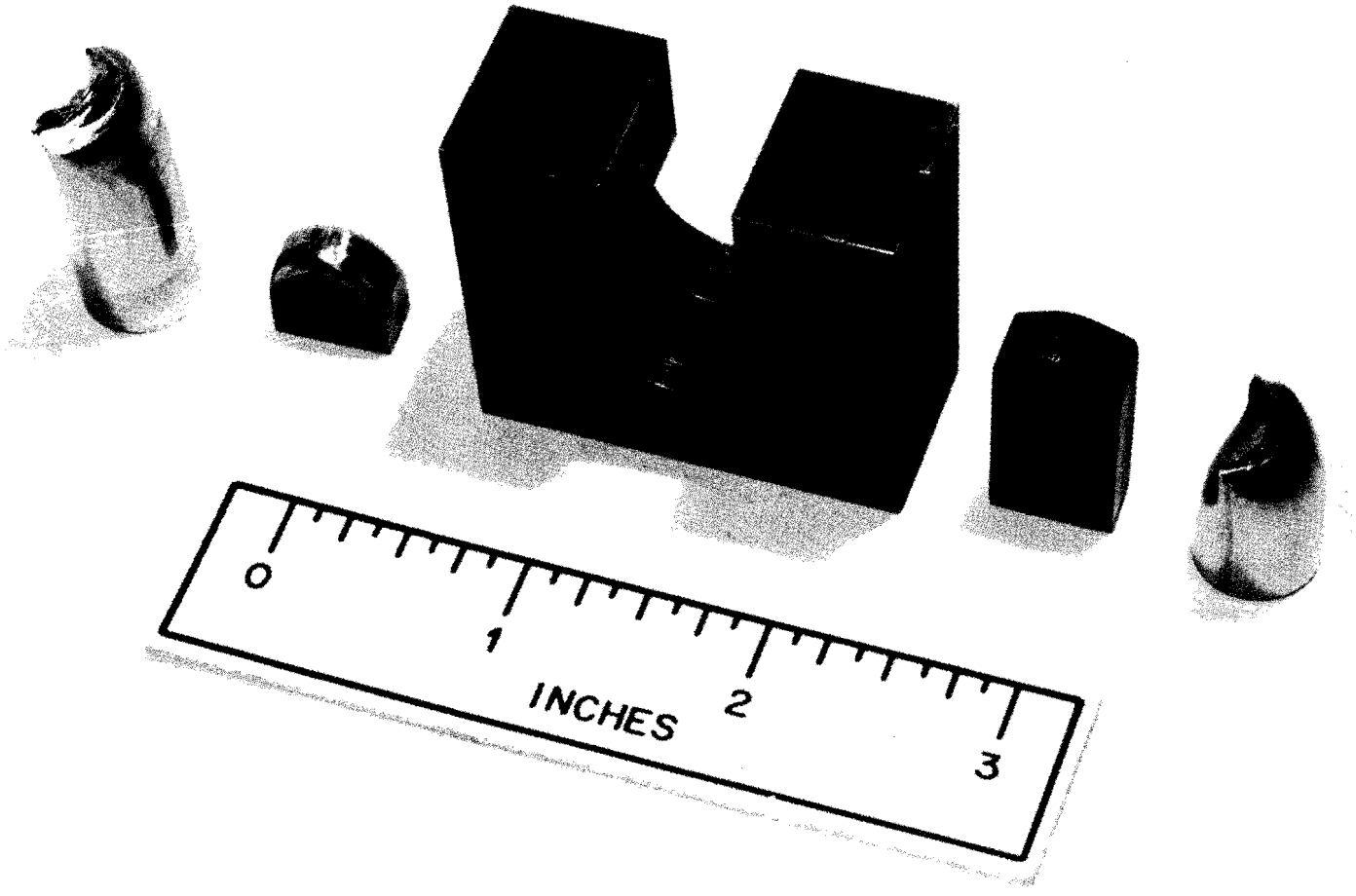

Fig. 19. Die No. 16.

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