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THE EXTRUSION OF COMPOSITE TUBES

M. R. D'Amore and H. Inouye

Metal flow in extruded seamless tube blanks has been studied at the Oak Ridge National Laboratory since September of 1954. The program had as ultimate goals:

1. The fabrication of seamless tubes in which the tube wall would be equal thickness layers of two different alloys.
2. The fabrication of seamless tubular fuel elements in which a powder mixture core of UO_2 and stainless steel would be clad on both sides with stainless steel.

The duplex tubes would find application in certain reactor heat exchangers where the inside and outside surfaces of the tubes are in contact with two different corrosive media. The tubular fuel elements could be used in sodium cooled reactors where efficient heat transfer could be obtained from their large surface to volume ratio.

The effect of the extrusion billet design on metal flow was first observed in composite extrusions of zircalloy jacketed in copper, and vanadium jacketed in mild steel. A cut-away sketch of the zircalloy billet design is shown in Figure 1. The front end of the zircalloy was tapered to reduce the possibility of a cladding rupture during extrusion. The billet was preheated at $1400^{\circ}F$ and extruded using a 9:1 extrusion ratio. The tapered front of the zircalloy in the billet produced a long taper in the extruded tube. The long taper was undesirable since it reduced the recovery of uniform thickness of zircalloy tubing.

The billet design was revised for the vanadium billets as shown in Figure 2. The nose of the billet was tapered 45° to conform to the entrance angle of the die and the ends of the vanadium were flat and parallel. The billet was preheated at 2100°F and extruded using a 7:1 ratio. A $4\frac{1}{4}$ inch long section cut from the front of the extruded tube is shown in Figure 3. The taper of the vanadium core is short and restricted to the front of the tube. The full thickness of vanadium was attained $4\frac{1}{2}$ inches from the front, and, thereafter, the clad and core were uniform to the tail of the extrusion. It was evident from these experiments that metal flow in an extruded tube could be altered by changes in the billet design.

A more complete knowledge of metal flow for the entire length of an extruded tube was desired before attempting the fabrication of duplex heat resisting alloys and the three-ply tubular fuel elements. A series of composite billets were designed to study the effect of various billet shapes on the flow pattern in duplex and three-ply extrusions. The first billets were constructed from hollow concentric cylinders of stainless and mild steel combinations. The cylinder walls were of equal thickness and the cylinders fit one inside the other to form the billet layers. The billets were preheated at 2100°F and extruded at a 9:1 extrusion ratio. The metal flow in the duplex tube extrusion is shown in Figure 4. The front section of the extruded tube shows that the initial metal flow was entirely in the inner layer of the billet. The metal flow of the outer layer was retarded by the friction between the billet surface and the container wall. The layers

Figure 1

(Unclassified)

Figure 2

(Unclassified)

(Unclassified)

Figure 3 (Y-13330)

Front section of steel clad vanadium tube extruded at 7:1 extrusion ratio. Dark material is mild steel.

in the central section of the tube were not of equal thickness but were uniform, while the layer thickness at both ends of the tube varied. The outer layer was 20% thicker and the inner layer was 20% thinner than a 1:1 ratio in the uniform section of the tube.

The flow pattern of the three-ply tube blank is shown in Figure 5. The metal flow is similar to that observed in the duplex tube blank. The inner and core layers were first to extrude while the outer layer was slightly retarded. Deviations from an equal thickness ratio in the uniform section of the tube were $+42\frac{1}{2}\%$ for the outer, $-6\frac{1}{2}\%$ for the core, and -36% for the inner layer.

The billet design was revised for the next extrusions based on the average layer thickness deviations observed in the previous tube blanks. The billet designs are shown in Figure 6. The three-ply billet was calculated to produce equal thickness layers and the duplex billet was calculated to produce an inner layer 0.096 inch thick and an outer layer 0.126 inch thick in the extruded tube blanks. The average thickness of the outer layer in the extruded three-ply tube was as calculated while the core was 0.006 inch thicker and the inner layer 0.005 inch thinner. The average thickness of the outer and inner layers in the uniform section of the duplex tube were 0.002 inch and 0.004 inch thicker than calculated, respectively. These experiments showed that any desired layer thickness could be obtained in duplex and three-ply extruded tubes by adjusting the starting layers of the billet.

The recovery of uniform thickness layers was only 45% due to

Figure 4 (Y-13936)

(Unclassified)

Flow pattern in a duplex stainless - mild steel composite tube extruded at a 9:1 ratio. Section 1 is front of tube. Dark metal is mild steel.

Figure 5 (Y-13935)

(Unclassified)

Flow pattern in a three-ply stainless - mild steel composite tube extruded at a 9:1 ratio. Section 1 is front of tube. Dark metal is mild steel.

Figure 6

the material loss at both ends of the extruded tubes. Two billets each of duplex and three-ply stainless mild steel combinations were designed in an effort to increase the material recovery. The design of a three-ply billet with a tapered nose is shown in Figure 7. A flat or tapered nose block was placed in front of the concentric cylinders of mild and stainless steel on each of the billets. The cylinder walls were of equal thickness and the cylinders were cut into one-half inch long sections. Molybdenum washers 0.010 inch thick were placed between each cylinder section and were thus spaced at one-half inch intervals along the length of the billet. The molybdenum washers served to outline the one-half inch long cylinders and to determine the deformation pattern across the tube wall. The four billets were preheated at 2100°F and extruded at a 9:1 ratio. The metal flow was found to be nearly the same in all the extruded tube blanks regardless of the shape of the nose. The metal flow in a tube blank extruded from a tapered nose three-ply billet is shown in Figure 8. The outer layer was thicker and the inner layer thinner than calculated by about 15%, while the core had reduced uniformly and was equal to the calculated thickness. An examination of the molybdenum markers showed that the deformation across the tube wall was complex. Tensile forces were observed near the outer and inner tube surfaces while compression was predominant in the central portion of the tube wall. The original 0.010 inch thick molybdenum washers varied in thickness from about 0.003 inch near the tube walls to 0.050 inch at the center.

The metal flow in a tube blank extruded from a flat nosed duplex billet is shown in Figure 9. The flow pattern is similar to that

Figure 7

THREE-PLY TUBE—FLOW PATTERN STUDY

OD: STAINLESS STEEL
ID: STAINLESS STEEL
CORE: MILD STEEL

Figure 8

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DUPLEX TUBE—FLOW PATTERN STUDY

OD LAYER: MILD STEEL
ID LAYER: STAINLESS STEEL

Figure 9

observed in the extruded three-ply tube. The inner layer was thinner and the outer layer thicker than the calculated values by about 15% in the duplex tube blanks. The results obtained in the extrusion of various billet designs are summarized in Table I.

Table I

The Effect of Billet Design on Composite
Tube Extrusion

<u>Billet Type</u>	<u>Average Layer Thickness</u>			<u>Length of Extrusion Containing Uniform Layers, %</u>
	<u>ID</u>	<u>Core</u>	<u>OD</u>	
	(inches)			
2-ply,no nose	0.087	---	0.132	45
2-ply,flat nose	0.109	---	0.140	63
2-ply,45°tapered nose	0.107	---	0.118	66
3-ply,no nose	0.050	0.073	0.111	45
3-ply,flat nose	0.070	0.074	0.103	55
3-ply,45°tapered nose	0.078	0.075	0.104	56

It can be noted that the use of a flat or tapered nose block results in higher recovery of uniform thickness material.

Duplex Extrusions of Heat Resisting Alloys

Based on the 15% average layer thickness deviations observed in the flow pattern studies, a duplex billet was designed to produce equal layer thicknesses in the extruded tube blank. The billet design is shown in Figure 10. The concentric cylinders were welded together at each end and a tapered nose block of type 316 stainless steel was welded to the front of each billet. Billets were assembled with and without evacuation of the gap between the cylinder walls. Three billets

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Figure 10

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each were prepared with outer layers of nickel, Monel, Inconel and Hastelloy B. The inner layer of all the billets was type 316 stainless steel. All of the combinations extruded without difficulty except the Hastelloy B clad type 316. The Hastelloy B layer had numerous circumferential cracks along the length of the extruded tube.

One tube blank of each combination was sectioned for examination. The layer thicknesses were about equal in all of the tubes regardless of the clad composition. A Monel clad type 316 tube blank is shown in Figure 11. The metal flow in the tube is characteristic of that encountered in all of the combinations extruded. Sections 16 to 19 $\frac{1}{4}$ inch long were cut from the remaining tube blanks and redrawn to 0.187 inch OD x 0.020 inch wall thickness tubing. The finished tubing was recently received at the Oak Ridge National Laboratory. A cross sectional view at 75X of the tube wall at three different locations along the length of the Monel clad type 316 redrawn tubing is shown in Figure 12. The layer thicknesses are about equal and are well bonded to each other. A longitudinal view of the nickel clad type 316 tubing is shown in Figure 13.

Simulated Seamless Tubular Fuel Elements

Concurrent with the duplex extrusions, four billet cans were prepared from type 316 stainless steel for a study of material flow in three-ply tubes containing powder mixture cores. A photograph of a three-ply composite billet assembly is shown in Figure 14. The core for two of the billets was prepared by hot pressing a powder mixture of type 302B stainless steel and 30 vol % Al_2O_3 . The other billets were

DUPLEX TUBE EXTRUSION

OD LAYER: MONEL
ID LAYER: TYPE 316 SS

Figure 11

Figure 12 (Y-18637)

(Unclassified)

Transverse view at 75X of redrawn monel clad type 316 duplex tubing. The tube layers toward center of photos are monel.

Figure 13 (Y-18638)

(Unclassified)

Longitudinal view of redrawn nickel clad type 316 tube wall. Top layer is nickel.

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THREE-PLY COMPOSITE BILLET ASSEMBLY

Figure 14

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filled by tamping a loose powder mixture into the billet can. The billets were evacuated to about 10 microns after assembly and the evacuation tube was sealed by hot-forging the tube. The four billets were extruded at 2100°F using various extrusion ratios. The extrusion ratio, method of core preparation, and the powder mesh size for each of the billets is tabulated in Table II.

Table II

Core Preparation Method and Extrusion
Ratio for Simulated Seamless Tubular Fuel Elements

Billet No.	Type	Core Density	Particle Size		Extrusion Ratio
			Al ₂ O ₃	302B	
1	Tamped Powder	55%	38-500	-100 mesh	5:1
2	Hot Pressed	80%	-140/325 mesh	-100 mesh	9.2:1
3	Tamped Powder	55%	-140/325 mesh	-100 mesh	21:1
4	Hot Pressed	89%	38-500	-100 mesh	21:1

Eighteen inch long sections were cut from the centers of both tube blanks extruded at a 21:1 ratio and redrawn to 0.187 inch OD x 0.015 inch wall thickness tubing. The fine diameter tubing was received recently but has not been completely evaluated. A view of the tube blank with a tamped powder core extruded at a 5:1 ratio is shown in Figure 15. The center flow of material during extrusion causes tapering at the front and tail of the core, and results in non-uniform layers in these areas. A photomicrograph of the extruded core is shown in Figure 16. The Al₂O₃ particles are slightly segregated but the stainless steel particles have bonded to form a continuous matrix.

The tube blank containing a hot pressed core extruded at a 9:1 ratio

Figure 15 (Y-18448) (Unclassified)
Material flow in a three-ply tube containing a
tamped powder core extruded at a 5:1 ratio. The
front of the extruded tube is on right.

Figure 16 (Y-18615) (Unclassified)
Photomicrograph showing a longitudinal view of a tamped
powder core after extrusion at a 5:1 ratio. Dark particles
are Al_2O_3 .

is shown in Figure 17. The layer thicknesses are nearly equal in this extruded tube and tapering of the core is again observed. Figure 18 shows a cross sectional view of the core-clad interface. The type 302B matrix appears bonded to the type 316 clad. Metallographic examination showed that the core was well bonded to the outer and inner cladding in all four of the extruded tubes.

Additional three-ply extrusions of type 316 stainless steel billets containing hot pressed and tamped powder cores of Al_2O_3 -stainless steel are being conducted. The billet designs are being revised in an effort to eliminate the tapered front and tail sections of the core and thereby improve material recovery. Fuel elements with UO_2 -stainless steel cores will be extruded when sufficient fabrication data has been obtained.

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THREE-PLY TUBE EXTRUSION

OD AND ID LAYERS: TYPE 316 SS
CORE: (Al_2O_3 -302 B)

Figure 17

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Figure 18 (Y-17901)

(Unclassified)

Photomicrograph showing transverse view of clad-core interface of a three-ply tube containing a hot-pressed core extruded at a 9:1 ratio. Type 316 clad is at top of photo. Dark particles are Al_2O_3 .

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