Cast Reformer Headers and Manifolds

Problems of stress, embrittlement, and cracking are virtually eliminated when manifolds have been cast centrifugally rather than made in the wrought form.

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An improved outlet manifold for reformer furnaces can be manufactured by the centrifugal casting process. Any combination of diameter and wall thickness is possible, and a lower cost manifold is obtainable than its wrought equivalent

Operating conditions for outlet manifolds in reformer furnaces are different from those of the associated catalyst tubes. Manifolds are not fired on their outside sufraces, and there is no catalytic reaction within them. Thus, there is only a small temperature gradient from inside to outside whose steepness is related to the efficiency of insulation. Once stable conditions have been attained after startup, the gases from the catalyst tubes mix in the manifold so that substantially uniform temperature conditions exist in the combined gas streams, and in normal operation changes in temperature are small and the rate of temperature change is low.

However, the horizontal position of a manifold combined with its long length and the restraints arising from pipe connections and the means of support give rise to severe stresses, particularly during startup and shutdown, probably reaching their maximum values in conditions of crash shutdown.

It follows therefore that the material from which the manifold is constructed should possess:

1. Sufficient strength at the operating temperature to resist internal gas pressure and stresses arising from pipe connections and manifold supports.

2. Adequate ductility at operating temperature together with sufficient room-temperature ductility after service to withstand startup and shutdown stresses. In other words, the alloy should not enbrittle unduly on aging.

In the early years of reformer furnace development, insufficient attention appears to have been paid to ductility requirements. Many manifolds were constructed from high-carbon, heat-resisting alloys such as HK40 (25/20 Cr/Ni) and HT/HU (37/18 Ni/Cr), all containing about 0.4% C. These alloys have moderate tensile ductility of 10-15% elongation at room temperature in the as-cast condition. But after exposure to reformer furnace operating temperatures for only a few hours, aging has already taken place to such an extent that the room temperature tensile ductility falls to an elongation of 4% or less. Using hind-sight, it is not surprising that cracking occurred in some manifolds, and site weld repair of the aged material proved difficult and in some cases impossible.

In the light of these experiences, there was a swing towards the use of a more ductile heat-resisting alloy. Alloy 800 in the wrought form, which did not depend for its high-temperature creep properties upon carbon content, was generally selected and successfully used for the manufacture of outlet manifolds. Welding materials and procedures were developed for fabrication.

The success of Alloy 800 in this application was often wrongly ascribed to its being in the wrought as distinct from the centrifugally cast form. The cause of the difficulties with the early cast manifolds was incorrect selection of alloy; it had nothing to do with the fact that they were manufactured from cast rather than wrought tubes. Alloy 800 proved successful largely because it was suficiently ductile at service temperature. Furthermore, its room temperature ductility after service was sufficient to resist, without cracking, the thermally and mechanically induced stresses to which manifolds are exposed.

At this point, some definition of "sufficient ductility" is necessary, which raises the question of evaluation of the significance of percentage elongation. Is 20% elongation twice as good as 10%? Indeed, is it any better at all? The numbers really do not mean very much. The question is "does the material behave in an essentially ductile manner?" Without laboring the point, in the context of outlet manifolds an arbitrary value of about 4% elongation can be used as a dividing line between essentially brittle and essentially ductile materials.

In developing a centrifugally cast alloy for this purpose, it was considered that a minimum of 25% creep ductility at a temperature of 800°C, and room temperature elongation of 10% after exposure to the same temperature, would provide a good margin of safety.

Niobium used to provide strength

In the development of the alloy it was apparent to APV Paramount Ltd. that low carbon content of the order of 0.10% was ncessary to avoid undue embrittlement after aging, and creep strength must be provided by another strengthening element. A research program was carried out employing niobium (columbium) for this purpose. A low-carbon nickel chromium niobium alloy having optimum mechanical and elevated temperature properties was developed. This was evaluated and designated "PARALLOY CR32W," with the following nominal composition in wt.-%: C, 0.10; Si, 0.8; Mn, 1.0; Ni, 32; Cr, 20; Nb, 1.3; S, 0.03; and P, 0.03.

Typical mechanical properties of centrifugally cast PARALLOY CR32W in the as cast and aged conditions at room temperature are shown in Table 1. Short-time elevated temperature properties of the alloy are shown in Table 2 and the long time elevated temperature stress-rupture properties in Table 3. Table 4 shows a comparison of creep-rupture ductility of PARALLOY CR32W and Alloy 800.

a suitable material for manufacture of outlet manifolds.

The welding procedure developed for fabrication of manifolds from Alloy 800 begins with welding the root run by the t.i.g. process using Inconel 82 wire. The weld preparation geometry is shown in Figure 1. After inspection of the root run, the weld is completed using Incoweld A by the manual metal arc process. Exactly the same procedure can be followed in welding centrifugally cast PARALLOY CR32W.

However, although there is a considerable record of satisfactory service experience with welds produced by this procedure, the weld efficiency at elevated temperature is fairly low, particularly at the upper end of the temperature range. In this context, weld efficiency is the strength of a weldment expressed as a percentage of the strength of the parent metal at the testing temperature.

To improve weld efficiency a procedure has been developed in which a welding rod whose composition matches that of the parent metal is used as a filler after completing the root run by the t.i.g. process using Inconel 82 wire. This matching weld metal technique results in considerably higher weld joint efficiencies at elevated temperatures, particularly at temperatures over 900°C as shown in Table 6.

Table 1. Room temperature tensile properties of cast 20/32/1 Cr/Ni/Nb heat-resisting steel

Property	As cast	Aged at 800°C (1462°F)				Aged at 875°C (1607°F)				
		100 hr.	250 hr.	500 hr.	1,000 hr.	100 hr.	250 hr.	500 hr.	1,000 hr.	4,000 hr.
Tensile strength lb./sq.in.	76,160	79,970	76,600	73,250	71,680	78,400	76,400	66,750	68,770	71,000
0.2% Proof stress lb./sq.in.	30,000	34,050	34,720	33,600	31,800	34,270	35,840	32,000	29,120	32,500
Elongation, %	32	16	17	15	14	22	17	11	12	17
RA %	21	15	19	17	13	19	14	11	14	20

Table 2. Short-time elevated temperature tensile properties of cast 20/32/Nb heat-resisting steel, typical values

Property	Temperature, °C				
	700°	750°	800°	850°	900°
Tensile strength lb./sq.in.	42,600	35,800	29,100	20,200	15,700
0.2% Proof stress lb./sq.in.	18,000	16,800	15,700	13,500	11,200
Elongation, %	40	35	50	60	66
R.A. %	45	40	60	65	70

In Table 1 it will be seen that even after exposure to a temperature of 800°C or 1,000 Hr., the room temperature ductility as measured by tensile elongation is 14%. Tests after prolonged aging at 875°C indicate that the alloy overages so that the elongation ductility reaches a minimum value of the order of 11% and subsequently increases.

A comparison of the mchanical properties of the two alloys in Table 5 shows that they are very similar. Consideration of the properties shown in Tables 1 to 5 indicates that centrifugally cast PARALLOY CR32W is in every way

Outside surface usually is machined

In the manufacture of manifolds, the centrifugally cast tube is bored to remove all traces of shrinkage porosity. It is usual to machine the outside diameter of the tube, although this is not considered essential. However, dye-check examination of the surface of the tube is greatly improved in sensitivity when it is smooth, and machining is the most practicable way of achieving this.

The cast lengths of individual sections of tube may be 12 ft. to 16 ft., but the precise length is engineered so that

Table 3. The stress rupture properties of cast PARALLOY CR32W (20/32/1.3 Cr/Ni/Nb 0.1%C) heat-resisting steel

Temperature °C	Temperature °F	Stress (lb./sq.in.) to produce rupture in 100,000 hr.
750	1382	5.500
800	1472	4.000
850	1562	2.800
900	1652	1.850
950	1742	1.100
1000	1832	610
1050	1922	310

Table 4. Creep-rupture ductility

ALLOY	% Elongation after rupture in: 1,000 hr. 1400°F	1,000 hr. 1600°F	1,000 hr. 1800°F	10,000 hr. 1400°F	10,000 hr. 1600°F	10,000 hr. 1800°F
PARALLOY CR32W (as-cast)	50	19	25	30	20	25
INCOLOY 800 (solution-annealed)	40	20	28	30	20	—

Table 5. Comparison of the mechanical properties of PARALLOY CR32W and INCOLOY 800H

Property	Paralloy CR32W (as cast)	Incoloy 800H Solution annealed
Room temp:		
Tensile strength, lb./sq.in.	76.000	80.000
0.2% proof stress, lb./sq.in.	30.000	40.000
Elongation, %	32	40
Rupture Strength:		
100.000 hr.. lb./sq.in.		
750°C	5.500	—
800°C	4.000	3.700
850°C	2.800	—
900°C	1.850	1.650
950°	1.100	—
1000°	610	690
1050°C	310	—

circumferential tube-to-tube welds will not coincide with the position of any outlets. Weld edge preparations are machined on the ends of the tube at the designed length. End caps are manufactured in PARALLOY CR32W as sand castings, machined all over and radiographically examined. The radiographic standard employed is ASTM E71 Class II for the end cap generally and Class I for the weld area. Weld preparation as shown in Figure 1 is machined on the end cap.

The main outlet from the manifold typically consists of a tee and a cone. The tee may be fabricated by saddling a piece of centrifugally cast tube and welding in position. Provided that a suitable welding procedure is adopted, a high standard of welding quality is maintained, the shape and extent of weld reinforcement is correctly designed and the weld is carefully inspected at all stages, this is perfectly satisfactory method of producing a tee. Alternatively, a cast tee may be employed in which case all internal casting surfaces are machined and a radiographic standard of ASTM E71 Class II for castings generally and Class I at the weld preparation area is maintained together with dye check examination of all surfaces.

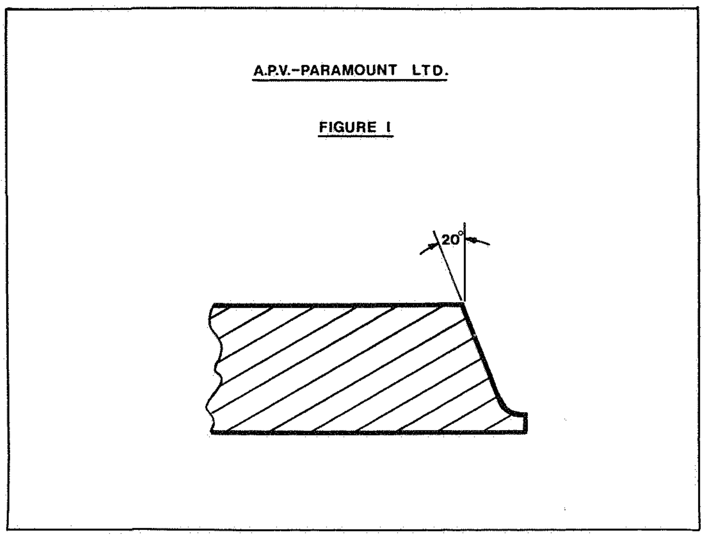

Figure 1. Weld preparation geometry.

The flanged cone is similarly manufactured from a casting machined all over and to the same standards of radiographic soundness and dye check integrity.

Building the manifold starts with putting on the end caps and making the tube-to-tube joints using the technique briefly described. Welds are radiographically examined to the standards of ASME Section VIII UW 51 and dye checked on the outside of the tee. The pipe legs so fabricated are joined to the tee and the inlet nozzles in the form of forged "Weldolets" are attached to the main tube.

The root run is made by the t.i.g. process using Inconel 82 wire, and the weld is completed with Incoweld A rod by

Table 6. Stress rupture properties of PARALLOY CR32W weldments

Test specimen	750°C Test data					900°C Test data				
	Stress lb./sq.in.	Life (hr.)	Weld strength efficiency	Elong. %	Site of fracture	Stress lb./sq.in.	Life (hr.)	Weld strength efficiency	Elong. %	Site of fracture
Parent material	10.528	2.190	—	4	—	4.422	2.006	—	4	—
Inconel 82 filler auto. TIG.	10.528	1.218	95%	2	Parent	4.422	308	56%	5	Weld metal
20/32/Nb filler auto. TIG.	10.528	1.594	99%	5	Parent	4.400	1.594.1	97%	5	Weld metal
Inconel 625 filler manual TIG.	12.500	1.187	98%	5	Weld	4.400	531	71%	5	Weld metal
Inconel 112 filler metal arc	12.500	1.135	97%	5	Parent	4.400	585	74%	1	Weld metal
Matching 20/32/Nb filler metal arc	10.528	883	90%	6	Parent	4.422	938	83%	6	Weld metal

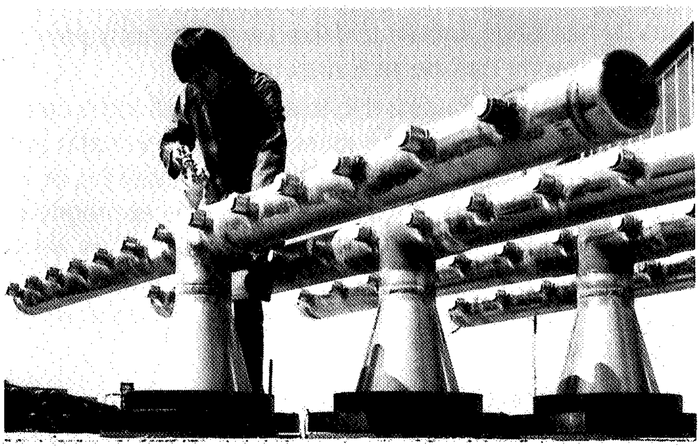

Figure 2. Typical manifolds of the short Topsoe type manufactured from cast Paralloy CR32W alloy.

the manual metal arc process. Drilling is then carried out through the tube wall in the usual manner and inside and outside surfaces dye checked.

Service experience

Outlet manifolds manufactured from centrifugally case PARALLOY CR32W have now been in service for several years in a number of locations throughout the world, in new plants and as replacements. No case of cracking or failure in any way has been reported. The use of this form of construction for outlet manifolds is now generally accepted and continues to increase.

The centrifugal casting process offers flexibility in that any combination of diameter and wall thickness of tube can easily be obtained, and the comparatively small quantity of tube needed for even a large manifold can be produced and delivered quickly. Finally, experience has shown that the cast manifold is somewhat cheaper than its wrought equivalent. #

BLACKBURN, J.

DISCUSSION

L.A. ZEIS, Pullman Kellogg: Are these put in service with either or both surfaces machined?

BLACKBURN: Both surfaces are machined. In the case of the outside surface, the machining is not essential in our view, but it certainly helps to machine the outside for the sake of extensive and sensitive dicheck inspection. It's somewhat difficult to dicheck really effectively on an as cast surface. The bore is machined, of course, to remove all traces of bore porosity. That is much the more important of the two things.

A point that is described in the paper that I haven't mentioned is that the attachments, the end caps, cones, tees, etc., are manufactured in the same alloy, principally as sand castings.

Q. How many hours did your creep tests last?

BLACKBURN: The slides and tables in the paper are based upon creep test results between 9,000 and 17,000 hours.

DON CLAPPER, American Cyanimid: My question is, what is the ductility figure you stated was desirable in these cast materials, 25%?

BLACKBURN: 25%, yes.

CLAPPER: My next question, have you enough time experience on these cast materials to see how well they are weldable after four or five years service? Have you seen weldability on these materials after the service?

BLACKBURN: No, we have not checked weldability after that length of service. A very good point. We have checked weldability up to the 4,000 hr. laboratory aging, which is part of the answer to your question, 4,000 hours is what? half a year or something, and the weldability is unchanged, as you would expect it to be from the ductility values that we get.

RON DYE, UKF Fertilizers, England: You mentioned that the root was T.I.G. welded and I gather that the weldout was with covered electrodes, i.e., coated Inconel 82. Then you talked about the matching weld material, and I assume this again was a T.I.G. root and covered electrode for the weldout.

BLACKBURN: It is, yes.

RON DYE: Have you any comment to make on what has been published in literature on the merit of the weldout by covered manual metal arc electrodes as opposed to complete automatic T.I.G. welding.

BLACKBURN: Automatic T.I.G. welding has the virtue of putting heat into the weld pool at the low and controlled rate resulting in the growth in crystals in the preferred direction in the weld operation. And this appears to be explanation for the high weld efficiency of the automatic T.I.G. welding, but we have not yet evaluated the improvement, if any, as compared with coated electrode. I would expect this would show an improvement.

RON DYE: This is interesting, from the point of view that UKF had HK40 alloy headers with cracked after 9,500 hr. service for reasons already mentioned in your speech.

BLACKBURN: Yes, Sir.

RON DYE: We then replaced these in a similar material to your own 20/32 Cr Ni Nb but made by another manufacturer, to-date these have performed satisfactorily. We have since retubed our furnace. I'm now talking about the catalyst tubes where we had difficulty in getting wrought material for the tube outlets. This is a Topsoe furnace, where the hot bottom outlets were made from wrought Incoloy 800. We had difficulty in obtaining Incoloy 800 for the new HK40 tubes outlets so we have substituted this new Spun cast 20/32 Cr Ni Nb material.

BLACKBURN: You've had good experience with that Ron, haven't you.

RON DYE: Yes — Thank you very much.

W.D. CLARK, ICI, Ltd.: Until the International Nickel Co. protested that there is no cast Incoloy. What we used, 18 Cr 37 Ni is rather similar to HU, and it has given really very good service, though there has been occasional trouble. For big transfer lines, for which Incoloy is very expensive, we and others have changed to refractory lined carbon steel, which is also not without its troubles as shown by various reports, including a paper in this session.

It seems to me Mr. Blackburn that you are showing us an alloy not particularly attractive for reformer tubes, where it is acceptable to run risks of sudden fracture in the search for high creep strength, but valuable for transfer lines because it maintains its toughness over its working life and can be acceptable where sudden fracture could cause danger to personnel. It has a strength at least comparable with Incoloy 800 and is cheaper, and may replace the refractory lined carbon steel which is common and regularly gives trouble.

BLACKBURN: You are absolutely right, of course. In my view this is not an ideal reformer catalyst tube alloy. Indeed, if you need a "better" catalyst tube alloy than HK40, you can do much better than this. The sole advantage of this alloy is in applications where its ductility does matter. In the case of catalyst tubes, low ductility has been known and lived with for many years, and apparently has no real drawbacks.

But I'm rather interested to think of something replacing a refractory lined, mild steel tube. Surely that's got virtually zero ductility, certainly the refractory bit of it, hasn't it? But for transfer line service in the appropriate temperature range, this low carbon material is very good. I wonder if you could tell us if the headers you refer to, in a so-called cast incoloy, what carbon level were they?

CLARK: 25.

BLACKBURN: Oh, well all right, that's a kind of accountant's choice really — it's neither one damn thing or the other, you know.

KEES VAN GRIEKEN, UKF, Holland: Did you make any investigations on segregation of alloy elements near the inside wall after normal boring that could affect the mechanical properties, e.g., the local creep ductility?

BLACKBURN: With the tube in the bored condition, having removed the bore porosity material, we have no evidence of any composition segregation across the remaining section.

VAN GRIEKEN: You realize that due to the shape of a tensile specimen you never get this part of the tube material in the gage length of the specimen.

BLACKBURN: We have looked for it. That is in the bored condition which is really the only sensible time to make such an examination. On a typical 3-4 in. tube we should be removing 3/16-in. from the bore. We have no evidence of any composition variation across the remaining wall section.