Heat exchanger and tube therefor

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Abstract
Heat exchanger tube (2), typically for an automotive heat exchanger, includes a core (6), external boundary surface (7) and internal boundary surface (5). The external boundary surface (7) includes zones devoid of material having melting point lower than the melting point of the core (6) and the internal boundary surface (5) includes material having a lower melting point than the core (6). Additionally or alternatively the external boundary surface (7) may include a layer of corrosion protection material and/or cathodic protection material.
The present invention relates to a heat exchanger and a tube therefor; in particular to a heat exchanger and heat exchange tube for vehicular use.

The use of aluminium alloys, and combinations of aluminium alloys, is widespread throughout the automotive heat exchanger industry. FIG. 1 illustrates the generalized construction of a prior art aluminium heat exchanger (1), where tube sections (2) are interspersed between airway sections (3), and constrained between section(s) (4) forming the collector tanks. Within the collector tanks (4) are located fluid entry and exit ports to facilitate the flow of that fluid requiring heat exchange within the unit. From these tanks, the tube sections (2) allow flow of fluid across the heat exchanger face area. Air is induced to flow across this face area, via the airways sections, and consequently exchange heat with the fluid in the tubes, thereby cooling the fluid within the tubes.

Such heat exchanger assemblies are conventionally ‘braze’d’ together, such that a lower melting point aluminium alloy (e.g. an Al—Si alloy) is used to form solid joints between parts 2, 3 and 4. To facilitate this joining process, the lower melting point alloy is typically provided as a cladding layer on the outer surfaces of the airway (3), the outer surface(s) of the tubes (2), and/or the outer surface(s) of the collector sections (4). Such a tube construction, using layers of lower melting point alloy (7) is illustrated in FIGS. 2A and 2B. The majority of the tube is constructed of the ‘core alloy’ (6), being an aluminium alloy chosen upon the basis of strength, density, cost and corrosion resistance. This core alloy can be clad upon either side by the same, or different alloys (5) and (7). Within some embodiments, the internal cladding alloy (5) is deliberately designed to be more electronegative with respect to the core alloy (6), and thereby inhibit corrosive attack from propagating into the core alloy.

The outer cladding (7) is conventionally chosen as an aluminium-silicon based alloy to facilitate brazing. In some instances, both internal and external claddings are chosen to be aluminium-silicon based to aid brazing, especially when internal tube joints are required. In an analogous fashion, when the collector tank assemblies are made using aluminium, a common alloy selection to those used in the tubes is chosen. Thus alloys used to construct collector tank assemblies are either singly or doubly clad, with at least one of those claddings being aluminium-silicon based. FIG. 3 illustrates the airway construction. Again, a core alloy (9) is chosen, typically for strength, cost and to offer cathodic protection to the tube core alloy (6). Under certain circumstances, an aluminium-silicon based cladding is utilized on the outer surfaces of the airway (8), to facilitate brazing.

During the brazing operation, the lower melting point aluminium-silicon based cladding is induced to flow across the surfaces of the core alloys, aided by controlled atmospheric conditions and the possible application of a flux. This is achieved by holding the heat exchanger assembly at a temperature above the melting point of the aluminium-silicon alloy, but below that of the core alloy. Thus the molten aluminium-silicon alloy pools within the joint regions of the heat exchanger, and when cooled, solidifies, thereby bonding the heat exchanger components together. This brazing mechanism has an associated disadvantage intrinsic to the flow of a molten aluminium-silicon alloy across a solid aluminium substrate. The substrate, in this instance the ‘core alloy’, will inevitably contain discontinuities within its metallurgical structure, such as crystal grain boundaries, atomic stacking fault defects and chemical segregation. Such defects can induce the diffusion of silicon from the molten alloy into their locality, and consequently erode the core alloy in these local areas.

Thus, after solidification is complete, the core alloy surface will exhibit evidence of localized penetration by the aluminium-silicon alloy. This localized penetration into the core is a disadvantage if that region of the heat exchanger surface is subject to cyclic stress during operational use. This region, because of its intrinsically different mechanical characteristics/behavior, can act as a site of stress concentration and induce cracking, which consequently compromises the integrity of the heat exchanger. Such cyclic stress might be induced by either thermal or mechanical means.

Certain heat exchanger assemblies incorporate tube designs with strengthening features to facilitate use within higher pressure systems. One such design, designated a ‘B-Type Tube’, is illustrated in FIG. 5. The central partition or seam 15 forms two discrete tube sections after brazing, which allows the tube to withstand much greater internal pressure. The alloy selection however has conventionally remained consistent to that for the generalized tube of FIG. 2. Designs such as the B-Type Tube incorporate an outer cladding (7) of an aluminium-silicon based alloy to facilitate brazing. The resultant stress concentrators developed after brazing, by the mechanism previously described, can have severe limitations upon the integrity of such tubes during cyclic stress. The outer cladding of aluminium-silicon alloy also has an additional, associated disadvantage during the brazing process, especially when used in conjunction with a core alloy with increased magnesium content (for strength increase). Within the B-Type Tube design, the ‘delta hole’ region 20 is illustrated in FIG. 6. Collector tanks 4 typically include a so-called tube plate 4A provided with substantially rectangular slots (with radiussed corners) to snugly receive the relevant end of the respective tube 2 (see FIG. 4). The delta region 20 forms an aperture or hole between the slot of the tube plate 49 and the surface of the tube due to the presence of the seam 15. This delta region must be filled with pools 16 of clad alloy prior to solidification, if a fluid-tight seal is to be achieved between the tube and the collector tank. By placing a melting clad layer on the outside of the B-Type Tube, this exacerbates the problem by increasing the delta size when the cladding becomes molten and flows. To overcome this effect, increased capillary action from the molten clad is required to fill this greater hole. This problem becomes increasingly difficult when higher strength core alloys, containing increased magnesium concentrations, are used in B-Type Tube construction. It is well known in the art that magnesium readily forms oxides during inert gas brazing, and such oxides have very high melting points. The presence of such oxides within the molten flux and molten clad alloy decreases fluidity, and consequently capillary flow. To avoid this problem, conventional B-Type core alloys have maintained magnesium levels below 0.05% by weight.

This invention describes a particular cladding choice for heat exchanger tubes, designed to minimize potential disadvantages and limitations.
0009 It has surprisingly been found that a reversal of the prior art situation in which the lower melting point aluminum-silicon cladding layer is not present on the exterior of the tube provides adequate brazing to the airway fins where aluminum-silicon clad airway fins are used. The performance characteristics of such tubes have been found to be improved also. Furthermore, and surprisingly B-type tubes have been found to braze adequately where the aluminum-silicon cladding is present on the interior rather than the exterior of the tube core material; the ability of the cladding material to be present on the interior rather than the exterior has again been found to improve the performance of the tube and consequently, heat exchanger performance.

0010 The principle underlying the invention is believed to have wider applications than in relation to aluminum-silicon clad cores.

0011 According to a first aspect, the invention provides a heat exchange tube having a tube wall including a core, an external boundary surface, and an internal boundary surface, the tube comprising a strip or sheet formed to define a plurality of flow paths and an intermediate seam comprising material of the tube wall, wherein:

0012 a) along its extent the external boundary surface of the tube wall is, or includes substantial zones, substantially devoid of material having a lower melting point than the core layer, (either as a cladding boundary layer or as material ingressing into the core); and,

0013 b) the tube wall has one or more zones of the internal boundary surface which includes material having a lower melting point than the core layer (either as a cladding boundary layer or as material ingressing into the core).

0014 According to a second aspect, the invention provides a heat exchange tube having a tube wall including a core, an external boundary surface, and an internal boundary surface, wherein the tube includes an external boundary layer of corrosion protection material and/or cathodic protection material, and along its extent the external boundary surface of the tube wall is, or includes substantial zones, substantially devoid of material having a lower melting point than the core layer, (either as a cladding boundary layer or as material ingressing into the core).

0015 In its broadest sense the tube may comprise a heat exchange tube (particularly a folded, roll-formed or welded tube) having internal and external surfaces comprising the core material without a respective internal and or external boundary layer present either upon manufacture of the tube and/or following any heat treatment of the tube (such as for example during brazing).

0016 Typically prior to brazing the lower melting point material will be present on the internal boundary of the tube wall as a cladding covering the core. Following heat treatment, the cladding melts and a proportion will ingress into the core material and solidify.

0017 The presence and degree of ingressing material is readily apparent upon microscopic examination of the tube.

0018 The invention is particularly suited to tubes for aluminum brazing, particularly where the lower melting point material comprises an aluminum alloy particularly an aluminum-silicon alloy (typically aluminum-silicon hypoeutectic alloy).

0019 The tube preferably has a core aluminum alloy desirably of high strength. For example core alloys containing strengthening elements such as Mg, Cu, Mn and/or other transition element additions. For example the tube could include a core aluminum alloy having magnesium substantially at or above 0.05% Mg.

0020 The tube is preferably of folded, roll-form or welded construction comprising a strip or sheet formed to define a plurality of flow paths and an intermediate seam comprising material of the tube wall. The tube is beneficially constructed from a strip or sheet formed to define a plurality of flow-paths and a longitudinally running seam, the seam comprising material of the tube wall, the tube wall having an internal boundary layer or surface comprising or having one or more zones of a lower melting point material than the core wall material. The longitudinally running seam is preferably positioned intermediate and separating adjacent running flow-paths.

0021 A vehicle heat exchanger including tubes according to the invention beneficially has a tube plate having an aperture through which the tubes extend, the tube plate having a layer or surface zone of material having a lower melting point than the core layer of the tube plate and tube.

0022 A vehicle heat exchanger according to the invention preferably includes a heat dissipation fin arrangement contiguous with the outer wall of the tube, the fin arrangement including a layer or surface including zones of material having a lower melting point than the core material of the fin.

0023 According to a further aspect, the invention provides a method of forming a heat exchange tube comprising deforming strip or sheet material including a core layer and a clad layer of lower melting point material than the core material, the deformation of the strip or sheet material being such as to form tube wall portions and a longitudinally running seam defining respective flow-paths in side by side relationship, the tube wall portions having the clad layer of lower melting point material on the internal, flow-path, side of the tube.

0024 The invention may be better understood with reference to the accompanying drawings in which:

0025 FIG. 1 is a schematic perspective view of a heat exchanger;

0026 FIGS. 2a and 2b are views of prior art heat exchanger tubes;

0027 FIG. 3 shows views of prior art fin/airway strips;

0028 FIG. 4 shows tube location in a tube plate;

0029 FIG. 5 shows a folded seamed heat exchange tube; and

0030 FIG. 6 is an end view of the tube of FIG. 5 showing in particular the “delta” region.

0031 A preferred design for a high-pressure heat exchanger is described herein. The tube (2) is of B-Type design (as shown in FIG. 5) with the inner cladding (5) comprising of an aluminum-silicon alloy to facilitate join-
A lower melting point alloy is avoided for the outer cladding (7), to minimize the formation of localised aluminium-silicon stress concentrators upon the outer surface of the final brazed tube. Indeed, the outer cladding (7) could beneficially employ an alloy choice to provide cathodic protection for the tube core (e.g. an aluminium-1% zinc alloy), or indeed an alloy choice with a reduced alloying element diffusivity, especially for silicon. It may be equally effective to eliminate the outer tube cladding (7) altogether, depending upon the choice of core alloy (6).

[0032] Such a tube construction does mean however that the airway (3) material requires an external cladding (8) of aluminium-silicon based composition, to facilitate airway-to-tube bonding. Also, the aluminium sections forming part or all of the collector tank assemblies (4) will require external aluminium-silicon based claddings, again to facilitate bonding in those tube-to-tank regions.

[0033] By providing the lower melting point aluminium-silicon alloy (AA4343) cladding on the inner surface of the tube wall the increase in the delta hole 20 that would occur in the prior art tubes on melting of the external cladding of the tube (2) is avoided. The internal cladding layer upon melting during brazing flows by capillary action into the seam 15 and provides a sufficiently robust and sealed joint. The ingress of the molten material into the core metal is on the interior of the tube (rather than the exterior) and the stress concentrators so formed are less of a problem because the inside of the tube is in compression (not tension) during pressure cycling.

[0034] A further benefit of a cladding arrangement that incorporates an outer cladding that is not aluminium-silicon based is the ability to use higher levels (≥0.05% wt.) of magnesium in the core alloy. Consider the alloy AA7072, for example, employed as an outer cladding, in conjunction with a core alloy of ≥0.05% Mg, and an inner cladding of AA4343. The presence of a solid, AA7072 surface in the delta region can inhibit the creation of magnesium oxides within the flux in this region, by simply acting as a barrier between the magnesium in the core and the flux in the delta region. Fluidity in this region can thus be improved.

[0035] Two heat exchangers have been constructed, with identical collector tank and airway configurations. These heat exchangers differ in their orientation of the B-Type Tube material claddings. Heat Exchanger A utilizes an inner cladding of alloy AA7072, a core alloy of AA3003, and an outer cladding of AA4343. In Heat Exchanger B these claddings are reversed (i.e. an outer cladding of AA7072 and an inner cladding of AA4343, upon a core alloy of AA3003).

[0036] Heat exchanger A fails pressure pulsation below 90,000 cycles. Heat exchanger B with braze clad on the interior of the tube enabled a sound brazed joint to be achieved and passed pressure pulsation to 180,000 cycles.

[0037] The outer surface of tube (2) is in tension due to bending from tubeplate movement and internal pressure and if there is a clean surface with minimal ingress of cladding alloy into the core then fatigue initiation is delayed. Having cladding alloy ingress into the core on the inner surface is not so detrimental as this region should be in compression on bending.

[0038] In practice there may be zones on the external surface of the brazed tube which exhibit ingress of cladding alloy into the core. This will however be present only in the supported zones where the tube surface contacts the airway (3) or the tube plate slots of the collector tank assemblies (4).

[0039] The loss of an inner corrosion clad is not an issue in a properly managed coolant system with correct longlife is antifreeze and corrosion inhibitors.

1. A heat exchange tube having a tube wall including a core, an external boundary surface, and an internal boundary surface, the tube comprising a strip or sheet formed to define a plurality of flow paths and an intermediate seam comprising material of the tube wall, wherein:
   a) along its extent the external boundary surface of the tube wall is, or includes substantial zones, substantially devoid of material having a lower melting point than the core layer, (either as a cladding boundary layer or as material ingressing into the core); and,
   b) the tube wall has one or more zones of the internal boundary surface which includes material having a lower melting point than the core layer (either as a cladding boundary layer or as material ingressing into the core layer).

2. A heat exchange tube according to claim 1, for use in a brazed aluminium heat exchanger, wherein the heat exchange tube comprises at least a core aluminium alloy.

3. A heat exchange tube according to claim 1 or claim 2, wherein the lower melting point material comprises an aluminium alloy.

4. A heat exchange tube according to any preceding claim, wherein the lower melting alloy comprises an Aluminium-Silicon alloy (typically Aluminium-Silicon eutectic alloy).

5. A heat exchange tube according to any preceding claim including an external boundary layer of corrosion protection material and/or cathodic protection material.

6. A heat exchange tube according to any preceding claim comprising a core aluminium alloy of high strength.

7. A heat exchange tube according to claim 6 comprising a core aluminium alloy having magnesium substantially at or above 0.05% Mg.

8. A heat exchange tube according to any preceding claim of folded or roll-form construction.

9. A heat exchange tube according to any preceding claim comprising a strip or sheet formed to define a plurality of flow paths and a longitudinally running seam, the seam comprising material of the tube wall, the tube wall having an internal boundary layer or surface comprising or having one or more zones of a lower melting point material than the core wall material.

10. A heat exchange tube according to any preceding claim, wherein the longitudinally running seam is positioned intermediate and separating adjacent running flow paths.

11. A heat exchange tube having a tube wall including a core, an external boundary surface, and an internal boundary surface, wherein the tube includes an external boundary layer of corrosion protection material and/or cathodic protection material, and along its extent the external boundary surface of the tube wall is, or includes substantial zones, substantially devoid of material having a lower melting point than the core layer, (either as a cladding boundary layer or as material ingressing into the core).

12. A heat exchange tube according to claim 11, wherein the tube wall has one or more zones of the internal boundary
surface which includes material having a lower melting point than the core layer (either as a cladding boundary layer or as material ingressing into the core layer).

13. A heat exchange tube according to claim 11 or claim 12, for use in a brazed aluminium heat exchanger, wherein the heat exchange tube comprises at least a core aluminium alloy.

14. A heat exchange tube according to claim 12 or claim 13, wherein the lower melting point material comprises an aluminium alloy.

15. A heat exchange tube according to any of claims 12 to 24, wherein the lower melting alloy comprises an Aluminium-Silicon alloy (typically Aluminium-Silicon eutectic alloy).

16. A heat exchange tube according to any of claims 11 to 15 comprising a core aluminium alloy of high strength.

17. A heat exchange tube according to claim 16 comprising a core aluminium alloy having magnesium substantially at or above 0.05% Mg.

18. A heat exchange tube according to any of claims 11 to 17 comprising a strip or sheet formed to define a plurality of flow paths and an intermediate seam comprising material of the tube wall.

19. A heat exchange tube according to any of claims 11 to 18 comprising a strip or sheet formed to define a plurality of flow-paths and a longitudinally running seam, the seam comprising material of the tube wall, the tube wall having an internal boundary layer or surface comprising or having one or more zones of a lower melting point material than the core wall material.

20. A heat exchange tube according to claim 19, wherein the longitudinally running seam is positioned intermediate and separating adjacent running flow-paths.

21. A vehicle heat exchanger including a heat exchange tube according to any preceding claim.

22. A vehicle heat exchanger according to claim 21 comprising a tube plate having an aperture through which the tube extends, the tube plate having a layer or surface zone of material having a lower melting point than the core layer of the tube plate and tube.

23. A vehicle heat exchanger according to claim 21 or claim 22 comprising a heat dissipation fin arrangement contiguous with the outer wall of the tube, the fin arrangement including a layer or surface including zones of material having a lower melting point than the core material of the fin.

24. A method of forming a heat exchange tube comprising deforming strip or sheet material including a core layer and a clad layer of lower melting point material than the core material, the deforming of the strip or sheet material being such as to form tube wall portions and a longitudinally running seam defining respective flow-paths in side by side relationship, the tube wall portions having the clad layer of lower melting point material on the internal, flow-path, side of the tube.