OPTIMIZATION OF CAPILLARY ACTION & BRASS CONSUMPTION IN DIP-BRAZING OF ROADSTER BICYCLE FRAMES

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Resume

This paper describes the requirements of joint clearance between the mating parts, of lugged bicycle frame head, to be brazed by flow of molten filler material (brass) between the micro gap due to capillary action. Tolerance analysis was done to establish the practical requirements of clearances essential to facilitate the assembly of the bicycle frame tubes and mating head lugs. Consumption of brass was computed, by weight measurements, after dip brazing of the lugged joints. Excessive joint clearance between the mating parts was reduced, by cold compaction of the assembled joint on mechanical power press using a press tool. The compacted joints were dip brazed by dipping it partially in the molten brass. Comparison of tensile strength of the brazed joints was done with respect to the strength of parent steel tubes. Brazed samples were sectioned to confirm the flow of brass all along the length of the lugs with improved capillary action. Thickness of the micro layer of the brass between the lug bore and tube outer surface was measured on optical microscope. Reduction in brass consumption due to reduced clearance was estimated volumetrically between the contact area between the lugs and the tubes.

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1. Introduction

Dip brazing [1, 2] process is used in building the diamond shaped lugged frames of classic roadster bicycles [3, 4]. Lugged construction had been the primary method of assembling the roadster bicycle frames since early 20th century. Roadster frames are usually built from “Electric Resistance Welded” (ERW) [5, 6] CEW C1 type steel tubes push-fitted inside the socket shaped sleeves, known as lugs. The lugs are primarily formed out of hot rolled carbon steel strips [7]. For brazing, every lugged joint is manually dipped in the molten brass maintained at a temperature slightly higher than its liquidus point 900 °C for brass with 60 % Copper and 40 % Zinc by weight [8] and chemical composition as shown in Table 1.

Table 1

Chemical Composition of Brass (wt. %).

	Tin	Lead	Zinc	Iron	Aluminum	Nickel	Silicon	Manganese	Phosphorus	Copper
Sample 1	0.041	0.012	36.590	0.036	0	0.005	0.000	0.004	0.012	63.100
Sample 2	0.039	0.016	37.950	0.013	0	0.000	0.020	0.074	0.020	61.150

Brazing takes place due to the flow of molten filler metal, between the surfaces of metals to be joined, by the principle of capillary action. As the filler metal (brass) cools down, it gets hardened thereby forming a joint connecting the tubes and the lugs. For the development of an effective capillary force [9] on molten filler metal or simply capillary action in brazing of metals, it is important to maintain a fairly uniform clearance between the mating surfaces of the joint. The tensile strength of the brazed joint decreases when the clearance between the joint is increased. Ideally there should be a tight clearance in the range of 0.03-0.04 mm. Variation in tensile strength of the joint according to the clearance kept between the metallic surfaces to be brazed is shown in Fig. 1 [10, 11].

Due to the manufacturing inaccuracies like ovality in the bore of lugs and outer diameters of tubes, larger clearances become essential to ensure a push-fit assembly. Due to larger clearance in mating parts, capillary action gets affected drastically, thereby reducing the tensile strength of the joint as well as increasing the consumption of brass being the filler metal in the joint.

To improve the tensile strength of the brazed joint, the clearance between the mating surfaces is mechanically reduced by cold compaction of the joint as explained in Section 4. Before the brazing operation, the joint is compacted by a press-tool over a mechanical power press.

This applied research paper is focussed on optimizing the brass consumption during dip brazing of the roadster bicycle frame head joints. Capillary action in the joint had been improved by reducing the joint clearance by mechanical compaction. If the capillary action can be achieved effectively, there is no need to fully submerge the joint in the molten pool of brass. And little dipping of the joint in the molten brass can ensure flow of brass in the entire joint due to the capillary action.

2. Tolerance analysis of the frame head parts

Roadster bicycle frames of lugged type are built with many ERW type cylindrical steel tubes. Two or more tubes are connected to each other through intermediate socket type part called lug. Lug is a component formed from cold drawn steel sheet, which fits over the ends of the steel tubing. Various parts of a typical roadster bicycle frame for men are as shown in Fig. 2 [12].

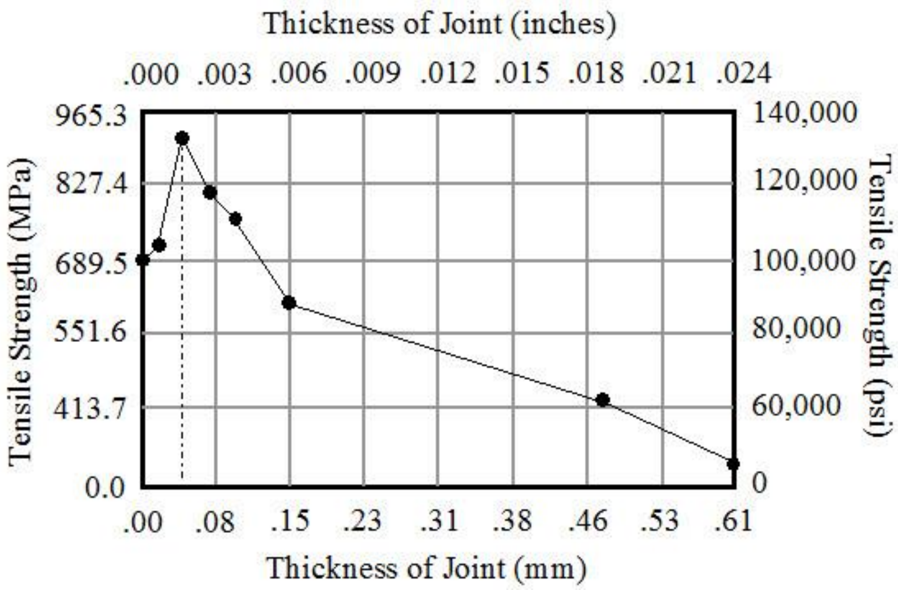


Fig. 1. Effect of joint clearance on tensile strength.

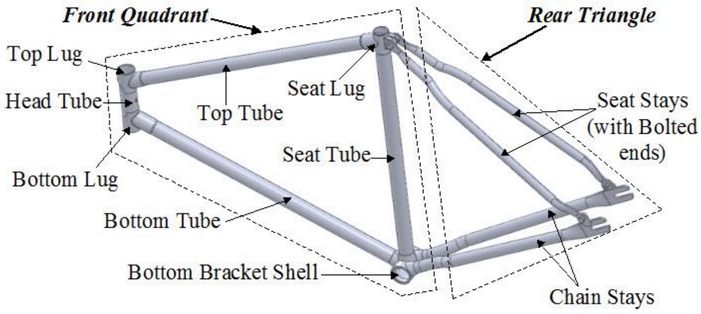
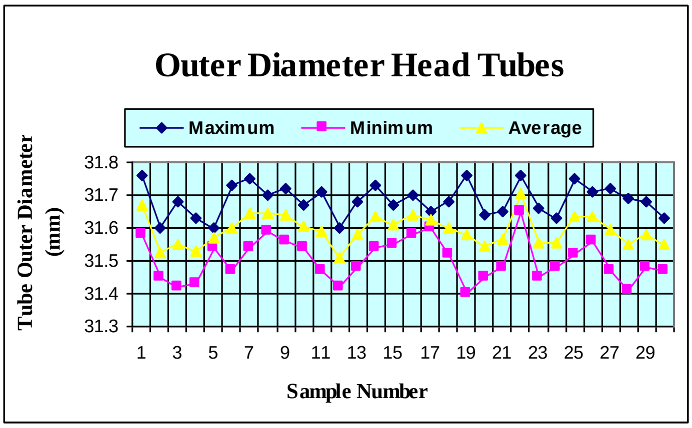
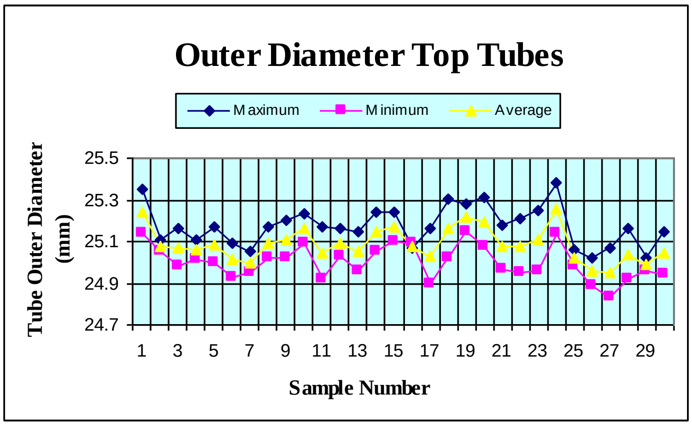


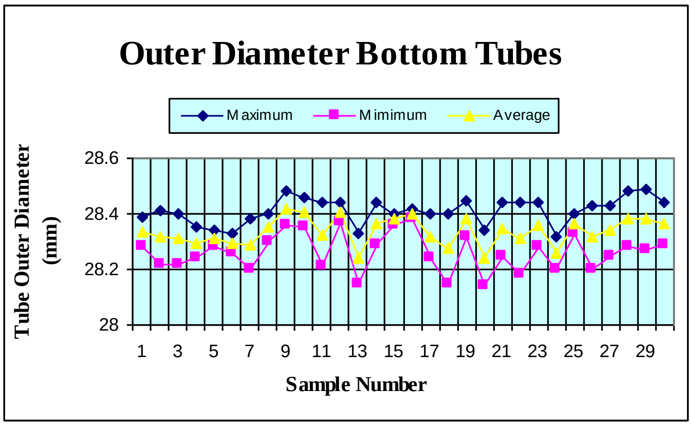
Fig.2 Roadster frame components.
(full colour version available online)



a) Max. of Avg. – 31.71mm ; Min. of Avg. –31.51mm



b) Max. of Avg. – 25.26mm ; Min. of Avg. – 24.95mm



c) Max. of Avg. – 28.42mm ; Min. of Avg. – 28.24mm
Fig. 3. Measured values of head tubes, top tubes and bottom tubes outer diameters.
(full colour version available online)

Table 2

Tolerance analysis - tube outer diameter in mm.

Tube and Nominal Outer Diameter	Specified limits		Average of Measured Values		Variance	Samples having Variance (%)	Reference Fig. No.
	Max.	Min.	Max.	Min.			
Head Tube φ31.75	31.80	31.62	31.71	**31.51**	0.11	66.70	3a
Top Tube φ25.40	25.40	25.27	25.26	**24.95**	0.32	96.70	3b
Bottom Tube φ28.57	28.60	28.44	28.42	**28.24**	0.20	100. 00	3c

Bold face "Average Measured Values" are beyond the specified limits; OD Means - Outer Diameter

Before making assembly of the joint, the samples of top tube and bottom tubes are cut to the required length within the specified tolerance. Then each end of the tube is cut to the shape by "Mitering" [13], so that it can rest closely against the side of the adjoining head tube, at an angle prescribed in the frame assembly. There are many methods of mitering the ends of the tubes, for instance milling, laser cutting, and coping or profile shearing using press tools. Coping is a much faster method to shape the ends of the tubes with fair degree of accuracy and is used in roadster bicycle frame tubes. The tubes with mitered ends are then push fitted into the respective lugs using pneumatically operated assembly fixture. For ease of assembly, using mass production assembly fixtures, and at the same time ensuring a reasonably tight fit assembly of tubes in the lugs, it is essential to keep an effective clearance 0.3-0.4 mm in the joint.

In order to confirm the development of sufficient capillary force during brazing, it is essential to know the true value of clearances in the joints formed when tubes are assembled in the respective lugs. This was done through a detailed tolerance analysis exercise as explained in Section 2.1, 2.2 and 2.3.

2.1 Tolerance analysis of tubes

Circularity of external diameters of head tube, top tube and bottom tube was practically measured on thirty samples of each type of tubes, randomly drawn from the mass production line. Average of maximum and minimum measured value of tube external sizes were calculated for every sample and the results are plotted in the graph shown in Fig. 3.

20 out of 30 samples (66.7 %) of head tube outer diameters were observed to be beyond the specified limits of 31.62 - 31.78 mm as shown in Fig. 3a.

29 out of 30 samples (96.7%) of top tube outer diameters were observed to be beyond the specified limits of 25.27 – 25.43 mm as shown in Fig. 3b.

30 out of 30 samples (100%) of bottom tube outer diameters were observed to be beyond the specified limits of 28.44 – 28.70 mm as shown in Fig. 3c. Results of Tolerance analysis showing the variations in the calculated average sizes as against the specified limits are shown in Table 2.

2.2 Tolerance analysis of frame head lugs

Similarly, circularity in socket bores of top lug and bottom lug was practically measured on thirty samples of each type of lugs, randomly drawn from the mass production line. Averages of maximum and minimum measured values of lug bore were calculated for every sample and the results are plotted in the graph shown in Fig. 4.

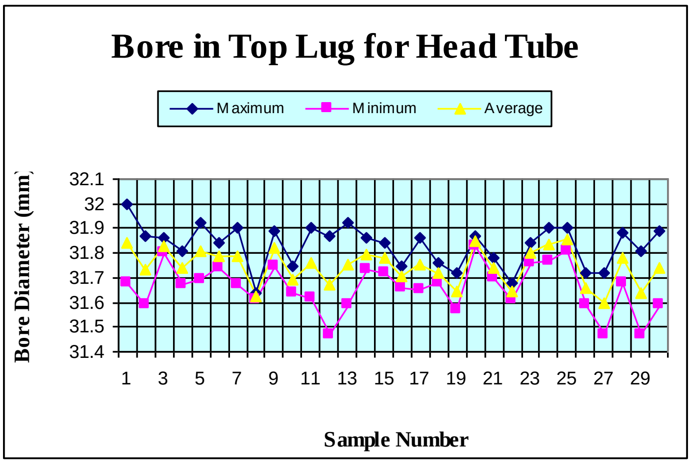
18 out of 30 samples (60 %) of bores in Top Lug for Head Tube were observed to be beyond the specified limits of 31.70 – 31.78 mm as shown in Fig. 4a.

7 out of 30 samples (23.3 %) of bores in Top Lug for Top Tube were observed to be beyond the specified limits of 25.42 – 25.80 mm as shown in Fig. 4b.

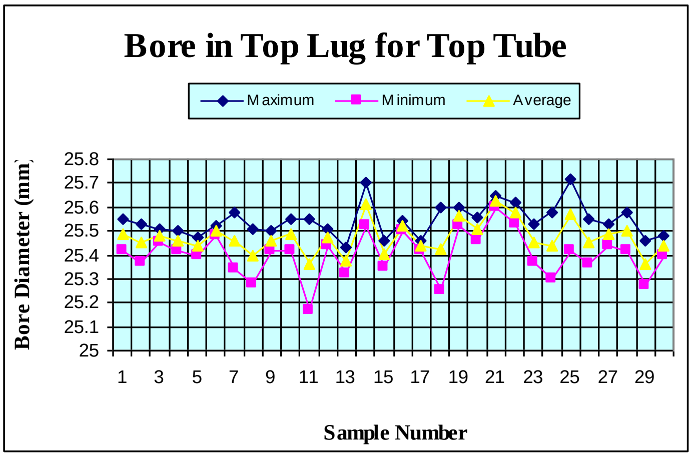
11 out of 30 samples (36.7 %) of bores in Bottom Lug for Head Tube were observed to be beyond the specified limits of 31.70 – 31.78 mm as shown in Fig. 4c.

24 out of 30 samples (80 %) of bores in Bottom Lug for Bottom Tube were observed to be beyond the specified limits of 28.60 – 28.68 mm as shown in Fig. 4d.

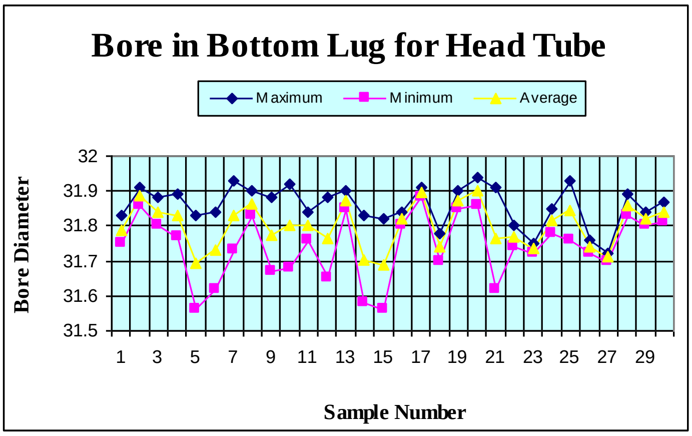
Results of Tolerance analysis showing the variations in the calculated average sizes as against the specified limits are shown in Table 3.



a) in top lugs for head tube



b) in top lugs for top tubes



c) in bottom lugs for head tubes
Fig. 4. Measured values of bore.
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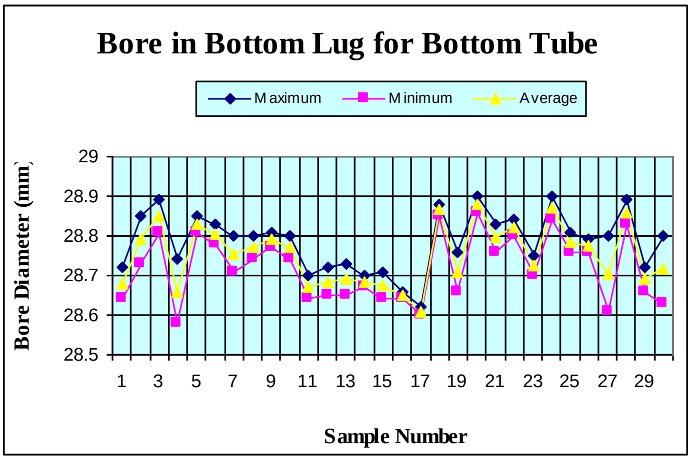


d) in bottom lugs for bottom tubes
Fig. 4. Measured values of tube bore.
(full colour version available online)

Table 3

Tolerance analysis – lug bore diameter in mm.

Frame Lug and Specified Bore Diameter	Specified limits Max.	Min.	Average of Measured Values Max.	Min.	Variance	Samples having Variance (%)	Reference Fig. No.
Bore in Top Lugs for Head Tube	31.78	31.7	**31.86**	31.60	0.08	60	4a
Bore in Top Lugs for Top Tube	25.5	25.42	**25.63**	25.36	0.13	33.3	4b
Bore in Bottom Lugs for Head Tube	31.78	31.7	**31.90**	31.69	0.12	36.7	4c
Bore in Bottom Lugs for Bottom Tube	28.68	28.6	**28.88**	28.61	0.2	80	4d

Bold face "Average Measured Values" are beyond the specified limits; Bore Means – Inner Diameter

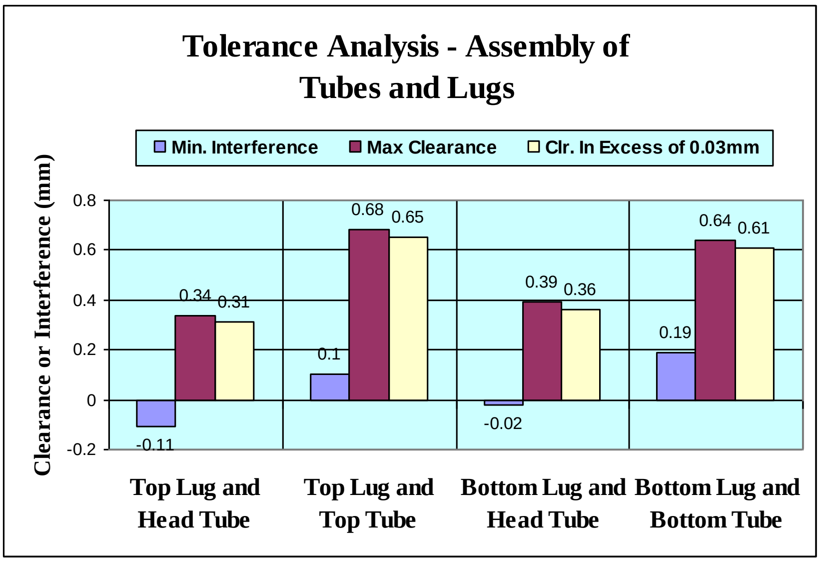


Fig. 5. Tolerance analysis - assembly of tubes and lugs.
(full colour version available online)

2.3 Tolerance analysis of tubes assembled in frame head lugs

Value of minimum interference, and maximum clearance was computed for the assembly of tubes with respective lugs. Minimum value of interference in the assembly was computed against minimum bore in the lug and the maximum outer diameter of the respective tube, based upon maximum material condition. And maximum clearance in the assembly was computed against maximum bore in the lug and the minimum outer diameter of the respective tube, based upon minimum material condition. Based upon the maximum clearance in the assembly of tubes and respective lugs, clearance in excess of 0.03 mm (being the best design clearance for dip brazing) was computed. Result of the final tolerance analysis of the assembly of tubes with respective lugs is shown in Fig. 5.

Due to large values of clearance in excess of the design clearance of 0.03 mm, between the lugged joints, the desired capillary action during the brazing remains virtually absent. Due to this it is necessary to fully submerge the joint in the molten brass, causing excessive consumption of brass.

2.4 Improvement of capillary action

In order to improve the capillary action during dip brazing, the initial clearance between the lugged joints can be reduced by the following actions.

2.4.1 At the tube design and procurement level

Clearance between the tubes and lugs can be brought down to some extent, by various dimensional control measures. Recommendations were made to narrow down the limits of design tolerance on the outer diameter of ERW tubes to 80 % of the specified tolerances, (within the comfortable limits of customized tube manufacturing) as shown in Table 4.

Table 4

Proposed tolerances on tube outer diameter.

Tube and Nominal Outer Diameter	Tolerance on Outer Diameter Existing	Tolerance on Outer Diameter Proposed
Head Tube φ31.75 Top Tube φ25.40 Bottom Tube φ28.57	(+0.03, -0.13)	(+0.03, -0.1) A bit tighter

2.4.2 At the frame manufacturing process level

Further reduction in clearances between the tubes and lugs is achieved by radial inward compaction of the pre brazed joints of the frame head by a press tool operation.

3. Computation of brass consumption in brazing

Joints namely 1) Head Joint, 2) Seat Lug Joint and 3) Bottom Bracket Shell joint are sequentially dip brazed in roadster bicycle frames [14]. Focus of this paper is on the improvement in dip brazing of the Head Joint as shown in the Fig. 6, being the area of largest consumption of brass among all the three joints.

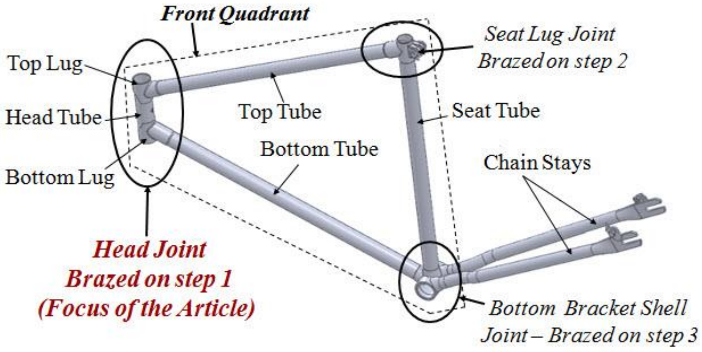
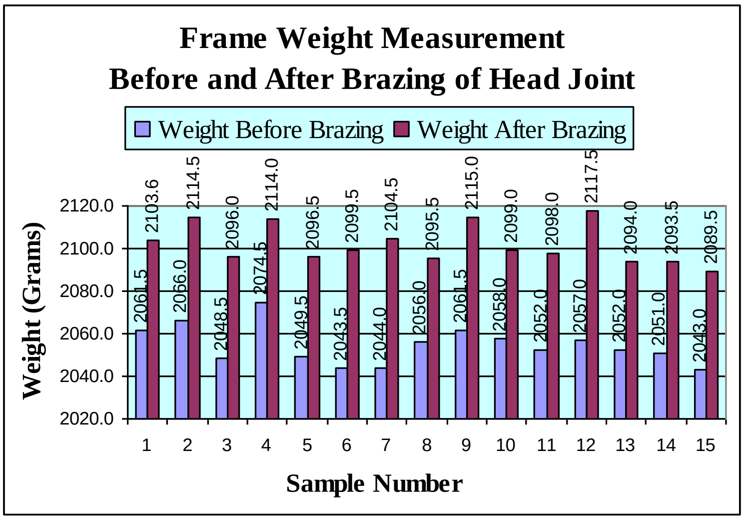
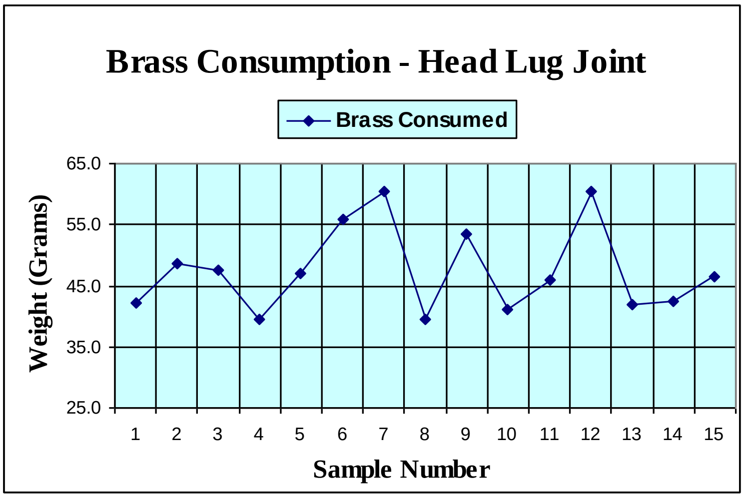


Fig. 6. Roadster frame components.
(full colour version available online)

Fig. 7 Dip brazing of head joint.
(full colour version available online)



a) frame weight measurement - before and after brazing of head joint



b) brass consumption during brazing of head lug joint

Fig. 8 Computation of brass consumed by weight measurement
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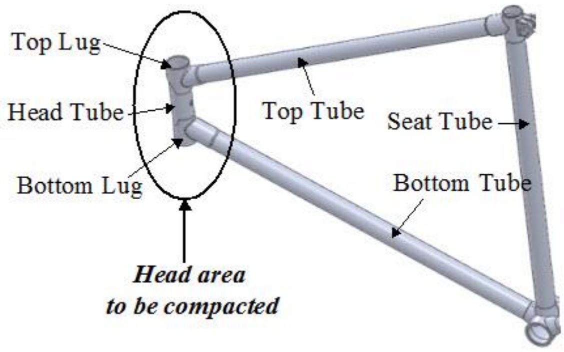

Fig. 9. Head joint area to be compacted.
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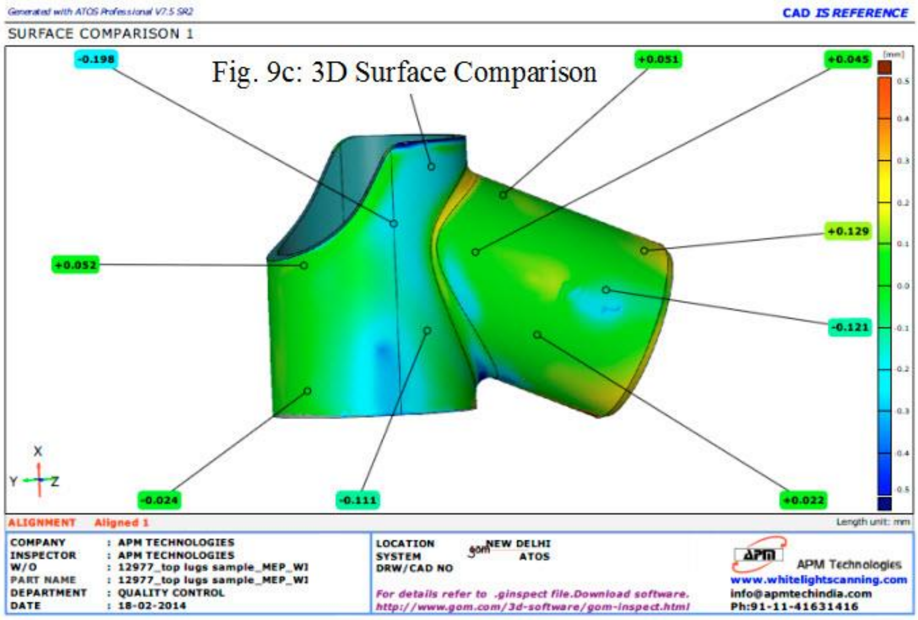
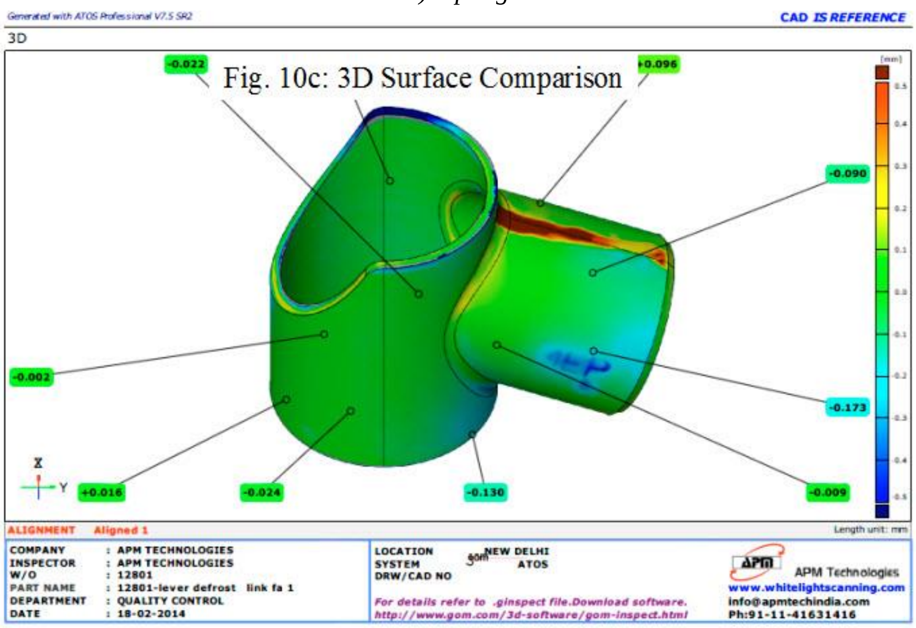


a) top lug



b) bottom lug

Fig. 10. Surface comparison after 3D white light scan.
(full colour version available online)

For estimating the brass consumption in brazing, fifteen samples of un-brazed front quadrants, were randomly drawn from the mass production line. Dip brazing was carried out for head joints consisting of "Top-lug joint" (joint of "Head Tube" and the "Top Tube") and "Bottom lug joint" (joint of "Head Tube" and the "Bottom Tube") as shown in Fig. 7.

Amount of brass consumed in brazing was computed from the difference in weights of frame before and after the brazing as shown in Fig. 8a.

The results of brass consumption in brazing of head lug joint are shown in Fig. 8b.

4. Compaction of the joints before brazing

Excessive joint clearance between the tubes and the lugs can be most effectively reduced by squeezing the joint dynamically on mechanical power press using a pair of compacting dies. According to the focus of this research paper, the compaction process was demonstrated on head joints as shown in Fig. 9

4.1 Designing of the joint Compaction Dies

The joint can be uniformly squeezed all around, only when a pair of upper and lower dies is produced with their contour of internal surfaces exactly matching with the contour of outside surfaces of the lugs. To transfer the surface profile of the frame lugs on to the press dies, it is essential to firstly create a 3D profile of outside surfaces of the frame lugs through 3D scanning using white light scanner. Five samples each of "Top Lug" and "Bottom Lug" were randomly drawn from the mass production line. External surfaces of lugs were scanned on White-light 3D scanner at APM Technologies, New Delhi (India). Accuracy of 3D scanning was confirmed through comparison drawn between the actual surfaces of the lugs and the 3D surfaces generated during the white-light scanning as shown in Fig. 10.

Using the external surfaces of 3D solid model of the lugs generated from 3D white-light scan, cavities were produced in the 3D model of the upper and lower die blocks of the compaction die. To avoid stressing of the fillet portions, during the compaction process, fillet radii were increased by 1-2 mm and parting line chamfers were provided on the dies.

Internal surfaces of the compaction die cavities (upper and lower), were selectively offset outwardly in the material addition direction as shown in Table 5, so as to reduce the cavity volume of the die when fully closed. This reduction in the cavity volume, according to the initial clearance of the compaction die, is responsible to squeeze the assembled joint, when the die is fully closed under the mechanical pressure.

Table 5

Initial joint clearance and surface offset in compaction die.

Maximum design joint clearance for capillary action in brazing – 0.0 3mm			
Assembly	**Max. diametric clearance (mm) (From Fig. 5)**	**Max. radial clearance (mm)**	**Surface offset causing material addition in the compaction die (mm)**
Top Lug and Head Tube	0.34	0.17	0.14
Top Lug and Top Tube	0.68	0.34	0.31
Bottom Lug and Head Tube	0.39	0.20	0.17
Bottom Lug and Bottom Tube	0.64	0.32	0.29

4.2 Manufacturing of compaction dies and press tool

Upper and lower half of the die blocks were manufactured on CNC vertical machining centre. The die blocks were assembled in a press tool that can be mounted on the power press as shown in Fig. 11. Compaction was done on a hydraulic press (Capacity 60 Tonnes × stroke 100 mm). For better productivity, compaction can be done on mechanical power press as well.

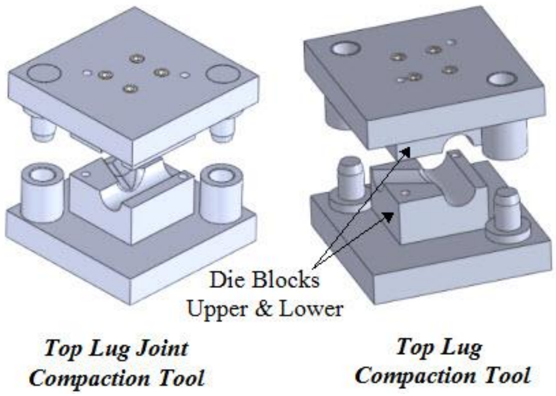


Fig. 11. Compaction press tools for head parts.
(full colour version available online)

4.3 Compaction process

Five sets of L-shaped samples, as shown in Fig. 12, were prepared for compaction trials before the brazing operation. Samples for compaction trials were cut from front quadrants randomly drawn from the production line.

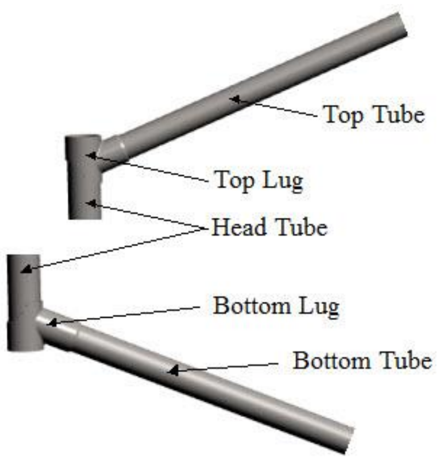


Fig. 12. Samples for joint compaction.
(full colour version available online)

4.4 Flow of material of lug during compaction

Once the assembled joint is radially squeezed from all sides by the mechanical pressure in the press tool, the material of the lug flows plastically in radial and axial directions. The radial flow takes place in inward direction and narrows down the clearance between the lug inner surface and the tube. The radial compaction is compensated by an axial outward flow of the lug material in the free direction. The amount of axial flow of material is quite negligible as compared to the highly significant radial inward flow under the mechanical restraint from the die.

The direction of flow of the “Top Lug” material during compaction process is shown in Fig. 13. Flow of material in the “Bottom Lug” is also on the similar lines.

5. Brazing and testing of compacted joints

5.1 Brazing of samples

Head lug joints were manually dipped in the molten brass in a crucible maintained at a temperature 905-910 °C. The compacted L-shaped samples of the “Top Lug” joint and “Bottom Lug” joint were dipped in the molten bath for a time period of 35-40 seconds. The metallic surfaces of connecting tubes and lugs get brazed together due to the flow of molten filler metal (brass) between them, by the development of capillary force. After this the joint is taken out of the molten bath and is allowed to cool down naturally in air. As the joint cools down, the filler metal (brass) gets hardened and forms a rigid joint between the tubes and the lugs. The head tube was cut from the middle and brazed samples of “Top Lug” joint and “Bottom Lug” joint were separated out. Samples of brazed joints are shown in Fig. 14.

5.2 Tensile strength testing

Tensile strength of each brazed joint between and the respective lug was done. Five sets each of L-shaped test samples of the "Top Lug" joint and "Bottom Lug" joint were prepared. The tensile tests were carried out on 40Tonnes capacity universal testing machine. The fixture used for tensile testing the samples is shown in Fig. 15.

During the tensile test, all the samples displayed a ductile fracture with neck formation from the middle of the longer tube (Top tube or Bottom tube) as shown in Fig. 16. The brazed joint did not display any type of fracture. Thus it was concluded that the brazed joints were stronger in tension than the parent tubes.

Breaking loads for the samples of head lug joints is shown in Table 6.

Table 6

Breaking loads in tension – head lug Joints.

Top Lug Joints		**Bottom Lug Joints**	
Sample No.	**Breaking Load (N)**	**Sample No.**	**Breaking Load (N)**
1	47880	1	36960
2	47760	2	36940
3	50260	3	36820
4	47640	4	36120
5	47560	5	36320
Max.	50260	Max.	36960
Min.	47560	Min.	36120
Average	48656	Average	36468

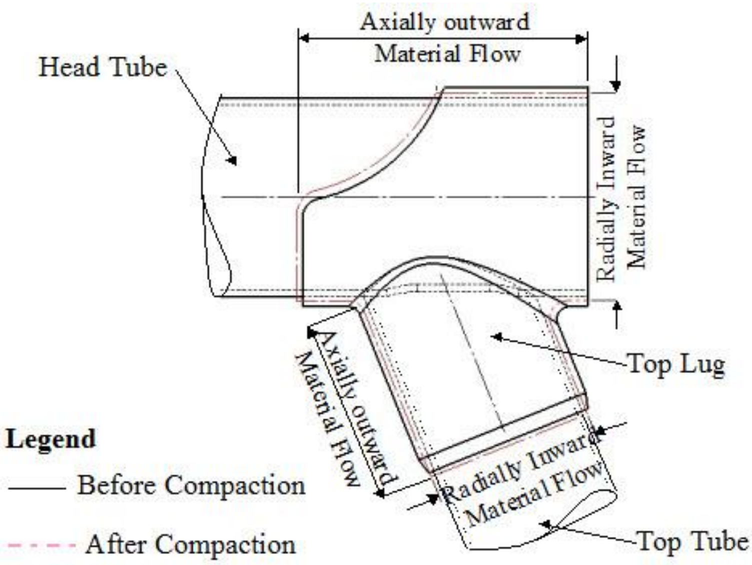


Fig. 13. Flow of materials during compaction.
(full colour version available online)

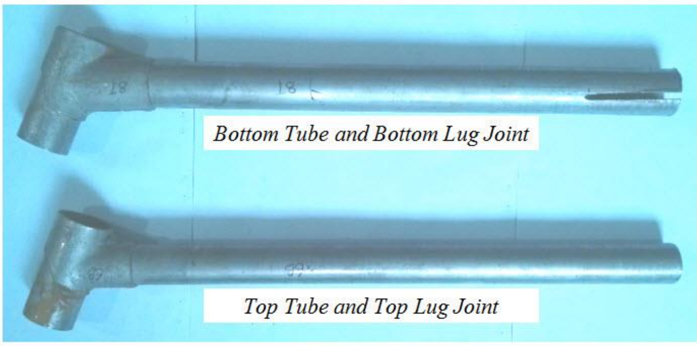


Fig. 14. Samples of joints for testing of tensile strength on universal testing machine.
(full colour version available online)

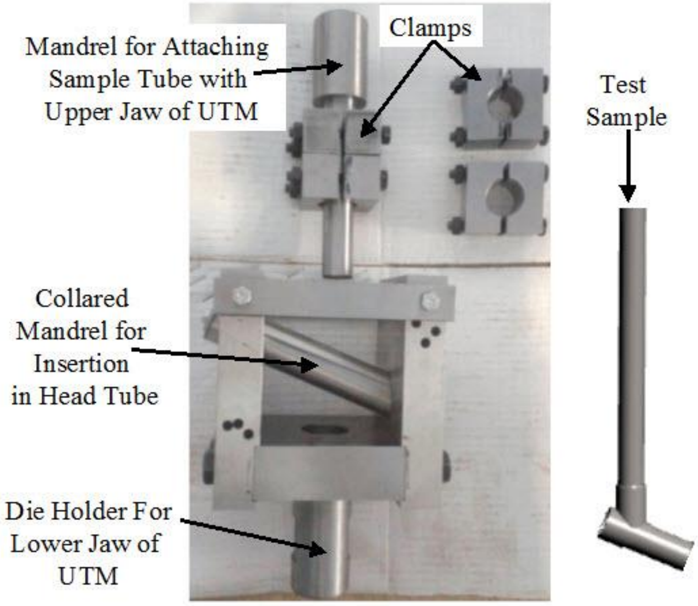


Fig. 15. Testing fixture and test sample for use on universal testing machine.
(full colour version available online)

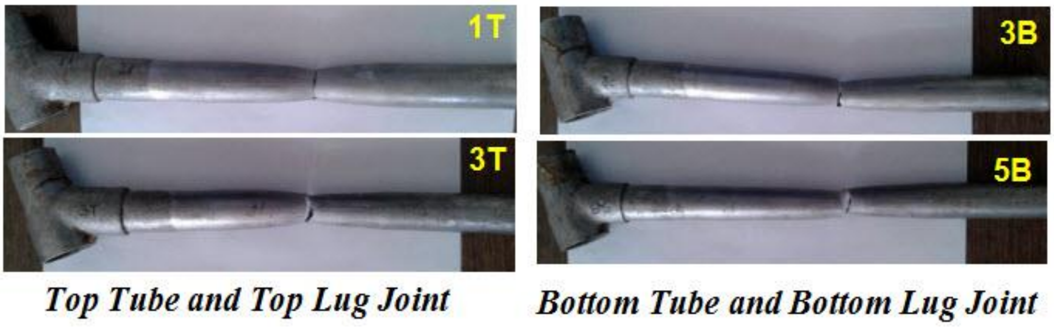


Fig. 16. Brazed joint samples tested on universal testing machine.
(full colour version available online)

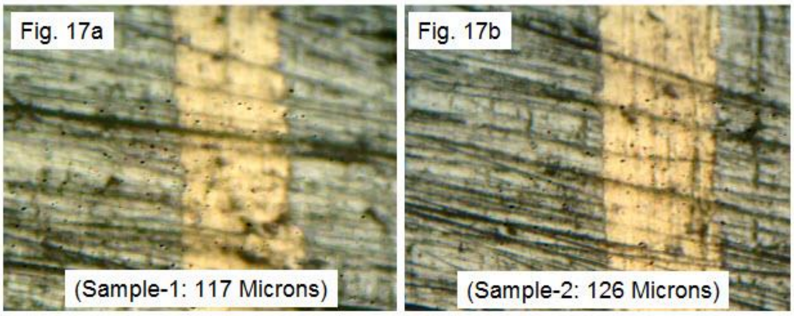
5.3 Measurement of brazing layer thickness

The “Top Lug” joint and “Bottom Lug” joint samples used in the tensile strength testing were sectioned across the central plane. The sectioned samples were ground flat, polished and etched to enable microscopic measurement of brazing layer thickness on an inverted microscope. Results of microscopic measurement of thickness of brass layer, under a magnification of 100× for “Top Lug Joint” is shown in Fig. 17.

Results of microscopic measurement of thickness of brass layer, under a magnification of 100× for “Bottom Lug Joint” is shown in Fig. 18.

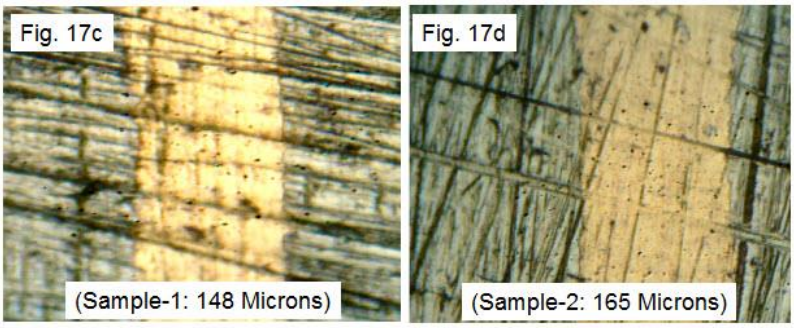
Comparison was drawn among joint clearance before compaction and after the brazing followed by compaction. The results of reduction in joint clearance due to compaction are shown in Table 7.

We can find some variance in measured thickness of brazing and the amount of radial compaction actually introduced in the compaction die. The variation in clearance is primarily due to 1) spring-back of the sheet formed lugs during press operation 2) inaccuracies during manufacturing of the compaction die.



Top Lug and Head Tube

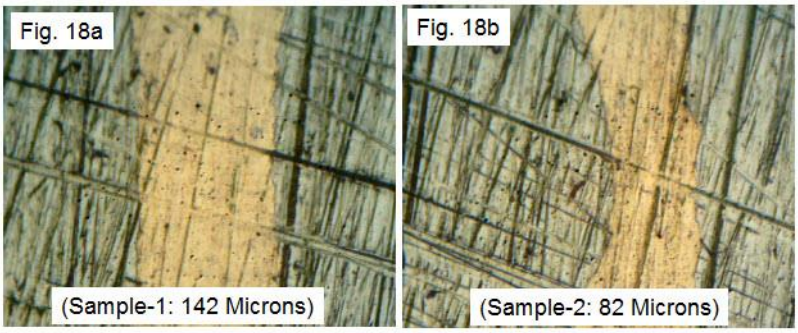
a) sample 1 top lug and head tube *b) sample 2 top lug and head tube*



Top Lug and Top Tube

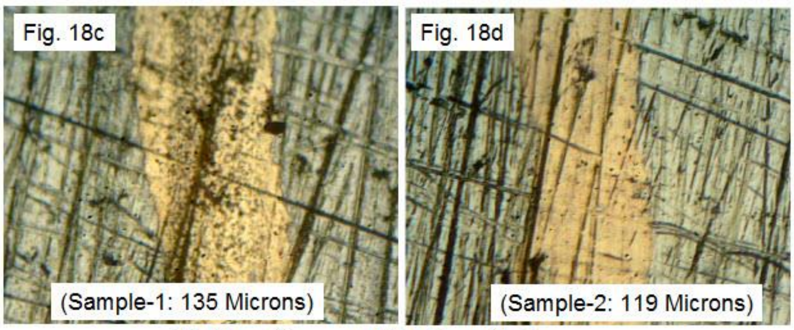
c) sample 1 top lug and top tube *d) sample 2 top lug and top tube*

Fig. 17. Brazing layer thickness in top lug joint.
(full colour version available online)



Bottom Lug and Head Tube

a) sample 1 bottom lug and head tube *b) sample 2 bottom lug and head tube*



Bottom Lug and Bottom Tube

c) sample 1 bottom lug and top tube *d) sample 2 bottom lug and top tube*

Fig. 18. Brazing layer thickness in bottom lug joint.
(full colour version available online)

Table 7

Joint clearance reduction after compaction (mm).

Sr.	***Assembly***	***Joint Clearance before compaction (As in Table 5)***	***Minimum brazing thickness after compaction***		***Reduction in joint clearance after compaction***	
			Values in 2 samples	***Average***	***Values in 2 samples***	***Average***
A	***B***	***C***	***D***	***E***	***F***	***G***
1	Top Lug and Head Tube	*0.34*	0.117 0.126	*0.122*	0.223 0.214	*0.218*
2	Top Lug and Top Tube	*0.68*	0.148 0.165	*0.157*	0.532 0.515	*0.524*
3	Bottom Lug and Head Tube	*0.39*	0.142 0.082	*0.112*	0.248 0.308	*0.278*
4	Bottom Lug and Bottom Tube	*0.64*	0.135 0.119	*0.127*	0.505 0.521	*0.513*

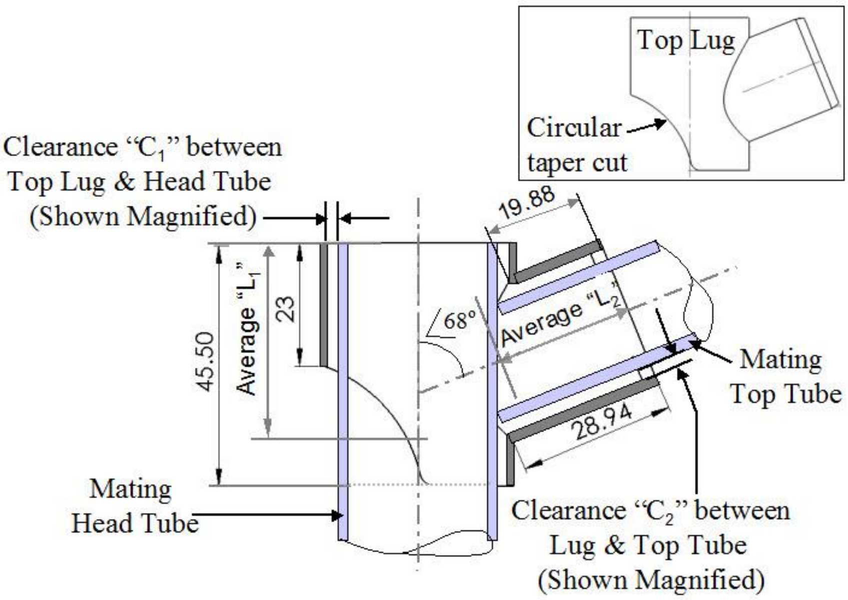


Fig.19. Volume of brass layer in top lug joint.
(full colour version available online)

6. Optimization of the brass consumption

Consumption of brass in brazing is directly proportional to the clearance between the joint. Hence to reduce the brass consumption it is necessary to reduce the joint clearance by squeezing the joint mechanically from all sides.

Quantity of brass – filler material trapped between the mating surfaces of the joint is estimated. Volumetric calculations of brass based upon the contact area between the lugs and the tubes are as under.

6.1 Volumetric calculations for Top Lug Joint

Various dimensions of "Top Lug" which are having relationship with contact area between the mating tubes are shown in Fig. 19. The clearances "C_1" – between the lug and the "Head Tube" and "C_2" – between the lug and the "Top Tube" have been shown magnified for clarity. First of all average lengths of engagement "L_1" and "L_2" of socket of the lug covering each tube is calculated from the maximum and minimum lengths of the trapezoidal-cut lugs.

Nominal outside diameter of the "Head Tube" (DH) = 31.75 mm.

Nominal outer diameter of the "Top Tube" (DT) = 25.4 mm.

Average length of cylindrical socket covering "Head Tube" {Term "L_1" as shown in Fig. 19} = (45.5 + 23) / 2 = 34.25 mm.

Average length of cylindrical socket covering "Top Tube" {Term "L_2" as shown in Fig. 19} = (28.94 + 19.88) / 2 = 24.41 mm.

6.1.1 Computation of joint clearance volume before compaction

Maximum clearance between "Top Lug" bore and "Head Tube" outside diameter {(Term "C_1" as shown in Fig. 19) and value as per Fig. 5} = 0.34 mm.

Clearance volume of cylindrical socket covering "Head Tube" (V_1) = $\pi \times DH \times L_1 \times C_1$ = $\pi \times 31.75 \times 34.25 \times 0.34 = 1161.5$ mm^3.

Maximum clearance between "Top Lug" bore and "Top Tube" outside diameter {(Term "C_2" as shown in Fig. 19) and value as per Fig. 5} =0.68 mm.

Clearance volume of cylindrical socket covering "Top Tube" (V_2) = $\pi \times DT \times L_2 \times C_2$ = $\pi \times 25.4 \times 24.41 \times 0.68 = 1324.5$ mm^3.

Total Clearance volume for both the sockets of the "Top Lug" joint = (V_1) + (V_2) = 1161.5 + 1324.5 = 2486 mm^3. (A)

6.1.2 Computation of joint clearance volume after compaction and Brazing

Joint brazing thickness between "Top Lug" and "Head Tube" {Cell value (E_1) - as per Table 7} = 0.122 mm.

Brazing volume of "Top Lug" socket covering "Head Tube" (V_3) = $\pi \times DH \times L_1 \times E_1$ = $\pi \times 31.75 \times 34.25 \times 0.122 = 416.78$ mm^3.

Joint brazing thickness between "Top Lug" and "Top Tube" {Cell value (E_2) - as per Table 7} = 0.157 mm.

Brazing volume of "Top Lug" socket covering "Top Tube" (V_4) = $\pi \times DT \times L_2 \times E_2$ = $\pi \times 25.4 \times 24.41 \times 0.157 = 305.8$ mm^3.

Total brazing volume for both the sockets of the "Top Lug" joint = (V_3) + (V_4) = 416.78 + 305.8 = 722.6 mm^3. (B)

Volume of brass saved in brazing due to compaction of "Top Lug" joint = (A) - (B) = 2486 – 722.6 = 1763.4 mm^3.

Density of 60:40 Brass = 8.525 g·cm^{-3}.

Reduction in consumption of brass in brazing after compaction of "Top Lug" joint = (1763.4×8.525) / 1000 = 15.1 g. (C)

6.2 Volumetric calculations for Bottom Lug Joint

Various dimensions of "Bottom Lug" which are having relationship with contact area between the mating tubes are shown in Fig. 20. The clearances "C_3" – between the lug and the "Head Tube" and "C_4" – between the lug and the "Bottom Tube" have been shown magnified for clarity. First of all average lengths of engagement "L_3" and "L_4" of socke of the lug covering each tube is calculated from the maximum and minimum lengths of the trapezoidal-cut lugs.

Nominal outside diameter of the "Head Tube" (DH) = 31.75 mm.

Nominal outer diameter of the "Bottom Tube" (DB) = 28.57 mm.

Average length of cylindrical socket covering "Head Tube" {Term "L_3" as shown in Fig. 20} = (47 + 27.39) / 2 = 37.2 mm.

Average length of cylindrical socket covering "Bottom Tube" {Term "L_4" as shown in Fig. 20} = (39.78 + 26.26) / 2 = 33.02 mm.

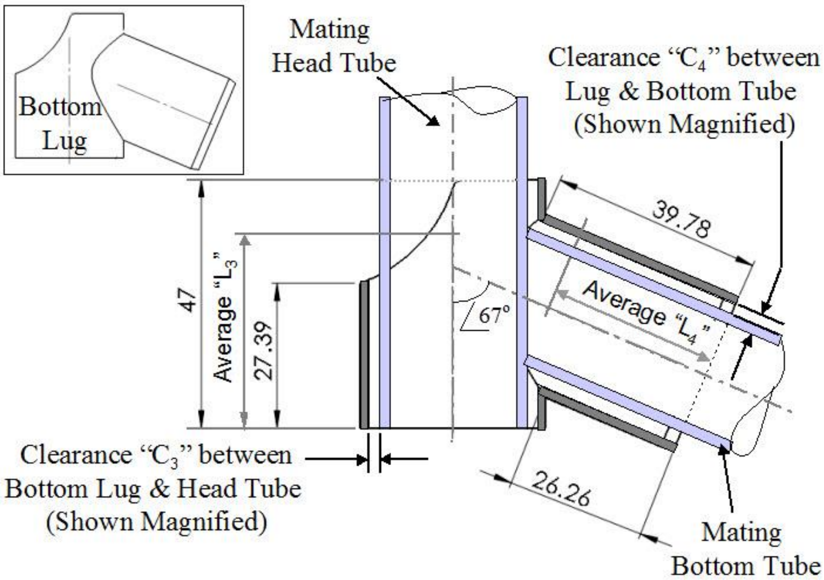


Fig. 20. Volume of brass layer in bottom lug joint.
(full colour version available online)

6.2.1 Computation of joint clearance volume before compaction

Maximum clearance between "Bottom Lug" bore and "Head Tube" outside diameter {(Term "C_3" as shown in Fig. 20) and value as per Fig. 5} = 0.39 mm.

Clearance volume of cylindrical socket covering "Head Tube" (V_5) = $\pi \times DH \times L_3 \times C_3$ = $\pi \times 31.75 \times 37.2 \times 0.39$ = 1447.1 mm^3.

Maximum clearance between "Bottom Lug" bore and "Bottom Tube" outside diameter {(Term "C_4" as shown in Fig. 20) and value as per Fig. 5} = 0.64 mm.

Clearance volume of cylindrical socket covering "Bottom Tube" (V_6) = $\pi \times DB \times L_4 \times C_4$ = $\pi \times 28.57 \times 33.02 \times 0.64$ = 1896.8 mm^3.

Total Clearance volume for both the sockets of the "Bottom Lug" joint = (V_5) + (V_6) = 1447.1 + 1896.8 = 3343.9 mm^3. (D)

6.2.2 Computation of joint clearance volume after compaction and brazing

Joint brazing thickness between "Bottom Lug" and "Head Tube" {Cell value (E_3) - as per Table 7} = 0.112 mm.

Brazing volume of "Bottom Lug" socket covering "Head Tube" (V_7) = $\pi \times DH \times L_3 \times E_3$ = $\pi \times 31.75 \times 37.2 \times 0.112$ = 415.6 mm^3.

Joint brazing thickness between "Bottom Lug" and "Bottom Tube" {Cell value (E_4) – as per Table 7} = 0.127 mm.

Brazing volume of "Bottom Lug" socket covering "Bottom Tube" (V_8) = $\pi \times DB \times L_4 \times E_4$ = $\pi \times 28.57 \times 33.02 \times 0.127$ = 376.4 mm^3.

Total brazing volume for both the sockets of the "Top Lug" joint = (V_7) + (V_8) = 415.6 + 376.4 = 792 mm^3. (E)

Volume of brass saved in brazing due to compaction of "Bottom Lug" joint = (D) - (E) = 3343.9 – 792 = 2551.9 mm^3.

Density of 60:40 Brass = 8.525 g·cm^{-3}.

Reduction in consumption of brass in brazing after compaction of "Bottom Lug" joint (2551.9 x 8.525) / 1000 = 21.8 g (F).

Total reduction in consumption of brass in brazing after compaction of the head part of the frame = (C) + (F) = 15.1 + 21.8 = 37.9 g (G).

The brass consumption as in (G) above can be compared against the existing average brass consumption of 47.5 grams as shown in Fig. 8b.

7. Conclusion and recommendations

7.1 Conclusion

It can be concluded that by carefully planned mechanical compaction of the tube and socket joint,

a) the joint clearance can be substantially reduced,

b) better capillary action can be achieved for an improved flow of brass,

c) partial dipping of the joint in molten brass is able to cause adequate flow of brass,

d) consumption of brass can be reduced, without sacrificing the joint strength.

7.2 Recommendations

It is recommended to carry out more research to establish the extra amount of radial compaction in the die to compensate the spring-back action in the material of the sheet formed lugs, after removal of the compacting force by the die. Such an amount of extra compaction needs to be established by more iterative practical trials.

If need be, more number of stages of compaction to be added in the process, if compaction beyond 0.35 mm becomes necessary (to achieve 0.03-0.04 mm clearance ideally suited for an effective capillary action required for dip brazing).

It is recommended to extend the process of joint compaction in “Seat lug” joint and “Bottom Bracket” joint as well.

It is recommended to use the sheet formed lugs that are within the prescribed tolerance limits of +0.08 mm on the bore diameter.

It is further recommended to narrow down the tolerance on the outer diameter of steel tubes to +0.03-0.10 mm as described in Table 4, to optimize the initial clearance in the joints.

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