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Ötektik Kaynağı ve Ötektik Üzeri Sert Lehim Uygulanan Al-Cu Boru Bağlantılarının Mekanik Özellik ve Mikroyapılarının İncelenmesi

Uğur GÜNDÜZ[1], Ahmet DEMİRER[2]

[1]Sakarya University Of Applied Science, Graduate Education Institute, Mechanical Engineer, Turkey

[2]Sakarya University Of Applied Science, Faculty of Technology, Mechanical Engineer, Turkey

e-mail: ugur024@gmail.com, ORCID ID:http://orcid.org/0000-0002-7019-7326

ademirer@subu.edu.tr, ORCID ID:http://orcid.org/0000-0003-1252-9203

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Anahtar Kelimeler
Alüminyum boru; Bakır boru; Soğutma sistemi; Sert lehimleme; Ötektik bağ; Sızdırmazlık.

Öz

Soğutma çevriminde en önemli faktörlerden biri olan sızdırmazlığın sağlanması için kuvvetli alüminyum bakır bağlantılarının oluşturulması gerekmektedir. Titreşimli bir ortamda çalışan bu bağlantılar aynı zamanda uzun süreli kullanımlar sonucunda meydana gelebilecek sızıntılardan kaynaklı gaz kaçaklarına engel olmalıdır. Bu çalışmada ötektik kaynağı ve ötektik üzeri sert lehim yöntemi ile birleştirilmiş alüminyum ve bakır borular incelenmiş, bağlantı mukavemetinin artırılması ve sızdırmazlığın sağlaması için bu iki yöntem tek bir bağlantı noktasına beraberce uygulanmıştır. Tüm numune çeşitlerine patlatma testi, çekme testi, sızdırmazlık testi uygulanmış olup, taramalı elektron mikroskobu altında bağlantı ara yüzeylerindeki mikroyapıları incelenmiştir. Yapılan deneysel çalışmalar sonucunda ötektik üzeri sert lehim bağlantısından kesme gerilmesinin diğer bağlantıya göre %15.32 daha yüksek sonuç elde edilmiştir. Ötektik üzeri sert lehim bağlantısı ile bağlanan numunelerin, ötektik bağlantıya göre %4,76 oranında basınca daha dayanıklı olduğu görülmüştür. Sızdırmazlık testleri sonucunda ise % 1 oranında olan sızdırmazlığın % 1 den % 0 oranına düşürüldüğü tespit edilmiştir.

Investigation Of Mechanical Properties And Microstructures Of Al-Cu Pipe Joints With Eutectic Welded And Brazed Over Eutectic

Keywords
Aluminum tube; Copper tube; Cooling system; Brazing; Eutectic bond; Sealing.

Abstract

In order to ensure tightness, which is one of the most important factors in the refrigeration cycle, strong aluminum-copper connections must be formed. These connections, which operate in a vibrating environment, should also prevent gas leaks caused by leaks that may occur as a result of long-term use. In this study, aluminum and copper pipes connected by eutectic and brazing method were examined, and these two methods were applied together to a single connection point in order to increase the joint strength and provide sealing. Explosion test, tensile test and leak test were applied to all sample types, and their microstructures at the junction interfaces were examined under scanning electron microscope. As a result of the experimental studies, the shear stress of the eutectic brazed joint was 15.32% higher than the other connection. It has been observed that the specimens connected with the eutectic braze connection are more resistant to pressure by 4.76% than the eutectic joint. As a result of the tightness tests, it was determined that the tightness, which was 1%, was reduced from 1% to 0%.

1. Introduction

Copper pipes, which are widely used in heating and cooling in the white goods industry, have been replaced by lower cost aluminum pipes due to rising costs. Aluminum copper pipe joining methods are used in heating and cooling system products such as evaporators, condensers, dryers, assembly kits. Secure connections are required for refrigerants to work and seal. Leaks occurring in aluminum copper connections used in products that have become a part of our lives such as air conditioners, tumble dryers and refrigerators that we use industrially or in our homes both prevent the products from fulfilling their functions and create formations that will endanger human health by the release of gases circulating in the system to the environment. Brazing welding methods are used alone for aluminum copper joints with additional connections so that the refrigerant gases do not leak out of the cooling system.

After the welding process, gas leaks may occur at the junction points of aluminum copper welds due to process, parameter, operator, environment or material. Keeping the flame long or short during the connection and applying the flame to the same point all the time may damage the connection area. The amount of humidity in the environment and dusty can be listed as environmental factors. Although the materials have been subjected to leak tests in the production lines where these connections are produced, leaks may occur in the connections during transportation, transportation and over time. During transportation, vibrations caused by loading can damage the joint points. Along with the developing technologies, manufacturing companies are working on the parameters that affect the welding quality and work to solve the sealing problems in the aluminum copper welding connection points (Ambroziak and others, 2020).

In this study, the application of eutectic and brazing welding together in order to prevent gas leaks in aluminum copper pipe connections used in the refrigeration sector has been studied. In both methods, the aim is to provide sealing by combining aluminum and copper pipes at the connection point. In order to increase the strength and life of the connection area, two methods were applied to a single connection.

In the studies of Watanabe T. and Hiroshi K. we see that such sources are expressed as eutectic sources instead of diffusion sources.

It is thought that this study will be beneficial especially for the companies that produce for the white goods sector or have gas leakage problems by joining aluminum copper pipe welding in their products.

2. Material and Method

In this study, eutectic and brazing joint method were applied together to reduce leakage problems and increase joint strength. By designing a blow-flaring form at the end of the aluminum pipe, eutectic connection was made first and brazing was applied on it. Experimental study results were compared with currently used eutectic and brazing connections.

2.1 Material

In the experimental studies, aluminum pipe material with the commercial name '1070 A (ASTM B 209)' was used. The chemical properties of 1070 aluminum material are given in Table 1 and mechanical properties of 1070 aluminum material are given in Table 2.

Table 1. Chemical properties of 1070 aluminum material (Nazari and others, 2016).

International Standard Number	Chemical Composition (%)				
	Al (min)	**Si** (max)	**Fe** (max)	**Zn** (max)	**Cu, Mn, Mg, Ti** (max)
1070 A (ASTM B 209)	99,7	0,20	0,25	0,07	0,03

Table 2. Mechanical properties of 1070 aluminum material (Yılmaz N. 2012).

International Standard Number	Tensile Strength (MPa min)	Yield Strength (MPa min)	% Elongation (min)	Hardness HBW
1070 A (ASTM B 209)	60	23	25	18

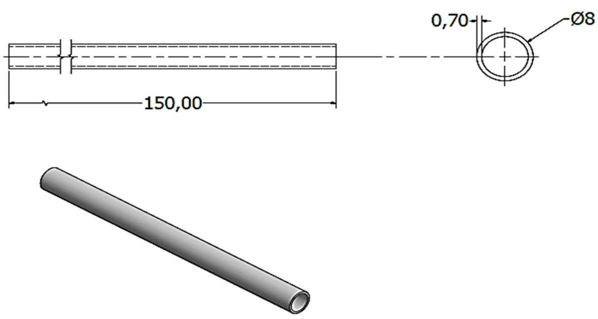

Figure 1. Flat end aluminum tube dimensions.

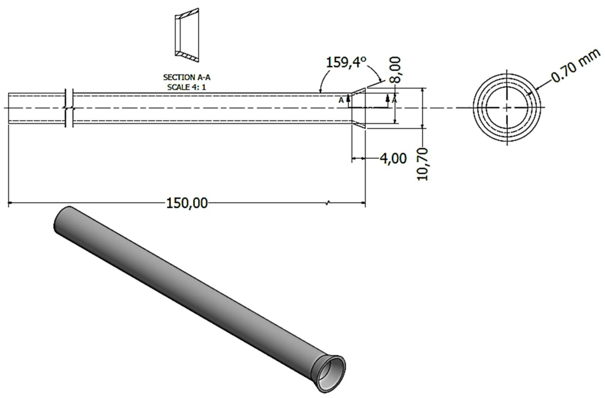

Figure 2. Flared end aluminum tube dimensions.

In Figure 1, the dimensions of the aluminum pipe with the eutectic connection are given. In Figure 2, the dimensions of the aluminum pipe with braze applied on the eutectic connection are given. In order for braze welding to be applied, a pool must be created for the filler metal to fill. In order to combine these two methods, the dimensioning of the pipe end countersunk details in Figure 5.2 has been made. Copper pipe with 'Cu-DHP' (Deoxidized high phosphorus residue copper) was used in experimental studies. The chemical components of the copper pipe are given in Table 3 and the mechanical properties are given in Table 4.

Table 3. Cu-DHP copper pipe chemical components (Shalaeva M. and others 2021).

Trade Name	Chemical Composition (%)	
	Cu	P
Cu-DHP	99	0,015-0,040

Table 4. Cu-DHP copper pipe mechanical properties (Shalaeva M. and others 2021).

Trade Name	Tensile Strength (MPa min)	Yield Strength (MPa max)	% Elongation (min)
Cu-DHP	220-260	140	33

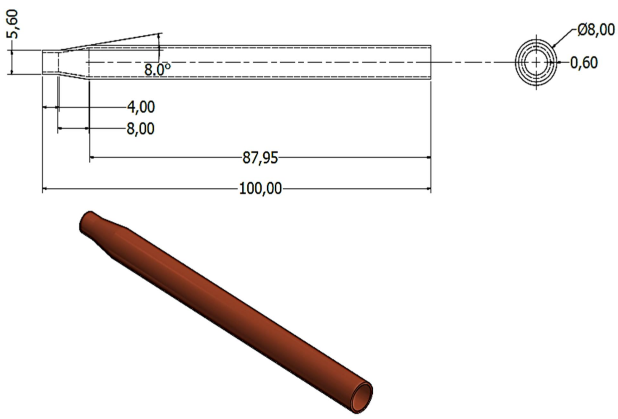

Figure 3. End shrink treated copper pipe dimensions.

Figure 3 shows the copper tube dimensions used in brazing application on the eutectic connection.

In the experimental studies, a self-flux ring form filler metal with the code 'A5.8-BAlSi-4' according to AWS standards was used. Chemical components of A5.8-BAlSi-4 filler metal are given in Table 5 and physical properties are given in Table 6. Filling material with the code AL 4047 was preferred because it is compatible with the area to be bonded due to the aluminum and silicon elements it contains, and because silicon increases the fluidity.

Table 5. Chemical components of A5.8-BAlSi-4 filler metal.

AWS Code	Brazing Temperature (°C)	Chemical Composition (%)
A5.8-BAlSi-4	582-604	0,01 Cu, 0,20 Fe, 0,01 Mn, 0,01 Mg, 12,08 Si, 0,05 Ti, 0,01 Zn, 88 Al

Table 6. Physical properties of A5.8-BAlSi-4.

AWS Code	Coler	Melting Degree (°C)	Yield Degree (°C)	Density (Lbs/in^3)
A5.8-BAlSi-4	Grimsi Beyaz	577	582	0,096

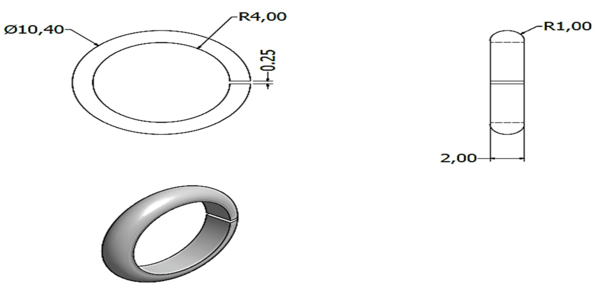

Figure 4. Dimensions of A5.8-BAlSi-4 brazing filler material.

In Figure 4, the dimensions of the self-fluxing filler metal in the form of a ring used during the application of brazing on the eutectic connection of the aluminum and copper pipe are given.

2.2 Method

2.2.1 Aluminum and Copper Tube Eutectic Connection Method

The aluminum pipe given in Figure 1 and the copper pipes given in Figure 3 were joined in the eutectic joining machine as shown in Figure 5. In the measurement made, the temperature of the connection point at the time of joining was measured as 563.7 °C. The aluminum and copper pipes, which were compressed with the molds of the eutectic connection machine, were heated and the connection was ensured by placing 10 mm into the aluminum pipe at 563.7 °C with the pressure applied to the copper pipe. After this temperature value was reached and the connection was made, the heating was cut off and the molds were opened (Yue and others, 2011). Eutectic connection was completed by melting the aluminum pipe and joining the copper pipe by pushing it into the aluminum pipe under pressure. (Ambroziak and others, 2020).

The welding surfaces of the aluminum and copper pipes were brought up to the eutectic temperature and immediately after the liquefaction occurred, they were pushed into each other under pressure and welded.

Figure 5. Combination of aluminum and copper tube and temperature measurement.

2.2.2 Brazing Application of Aluminum and Copper Pipe on Eutectic

Aluminum and copper pipes to be brazed on the eutectic connection were cut with a pipe cutting machine in the desired sample sizes. The copper pipe end was swaging with a pipe end swaging machine. In order to apply the eutectic connection inside the aluminum pipe and on the brazing, the tip detail form, the dimensions of which are given in Figure 2, is designed. In order to obtain this form, the punch, whose dimensions are given in Figure 9, is connected to the aluminum pipe end blowing machine and by entering 22 mm into the aluminum pipe end, the desired aluminum pipe end form is obtained (Hazawil and others, 2017).

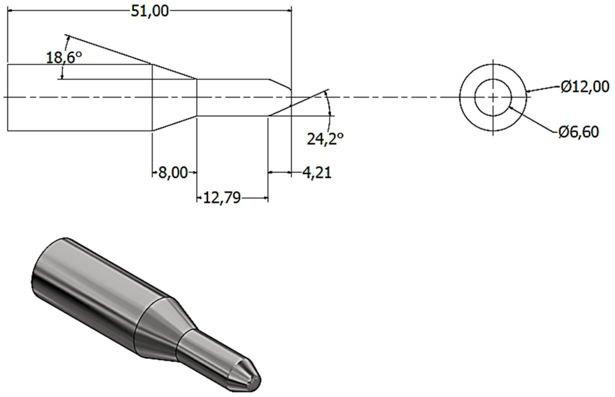

Figure 6. Brazing application punch on the eutectic junction.

The aluminum pipe given in Figure 2 and the copper pipe given in Figure 3 were first combined with the aluminum and copper pipe eutectic coupling machine. Eutectic connection was achieved by pushing the copper tube into the aluminum tube with a distance of 10 mm at 560 °C measured with a laser temperature measuring device. The aluminum copper tube obtained as shown in Figure 7 is placed at the junction point by passing an annular brazing phenomenon from the copper end of the eutectic connection joint (Jung and others, 2018).

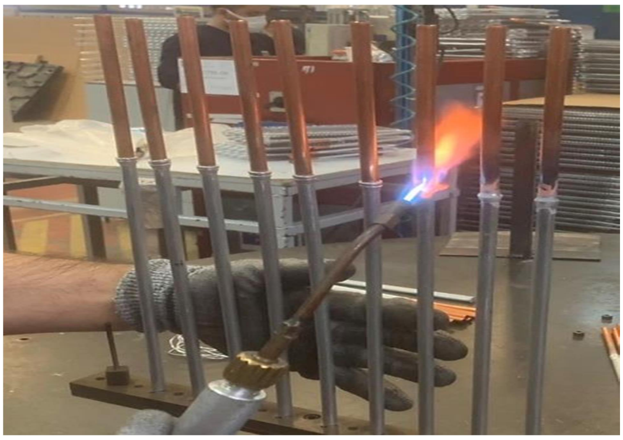

Figure 7. Applying brazing on the eutectic junction.

The application was carried out with the help of a blower. The brazing application was carried out with a mixture of natural gas at 1 bar and oxygen at 10 bar. The connection point was heated, allowing the brazing filler to reach its melting temperature. In the measurement made with the laser temperature measuring device, the brazing application on the eutectic connection was completed with the melting of the brazing filler at 590 °C (Oğuz B. 1988).

2.2.3 Images and Technical Dimensions of Connections

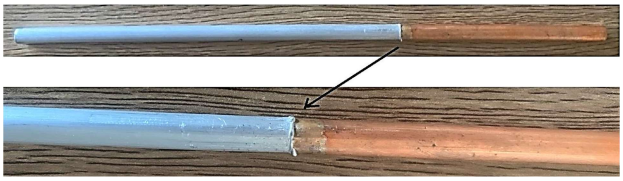

Figure 8. Image of aluminum-copper pipe eutectic connection.

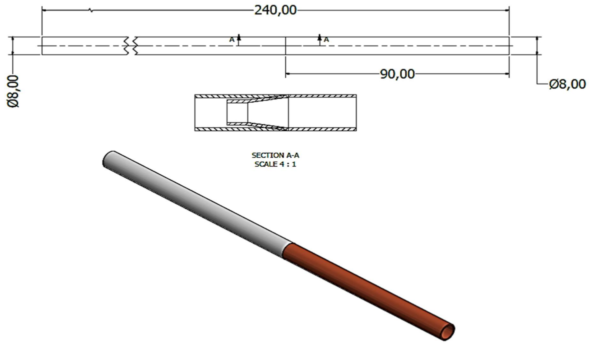

Figure 9. Dimensions of aluminum and copper pipe with eutectic connection.

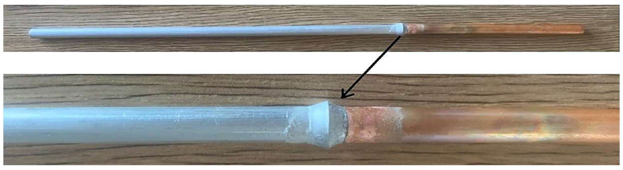

Figure 10. Image of brazing application on eutectic connection of flared aluminum-copper tube.

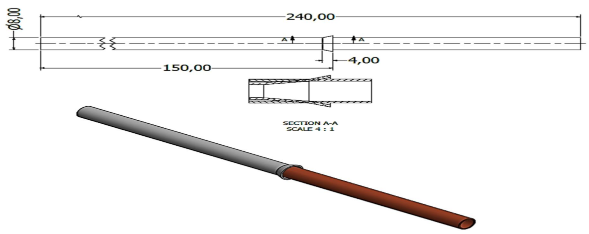

Figure 11. Dimensions of flared aluminum and copper pipe with brazed on the eutectic joint.

2.2.4 Tests and Reviews

2.2.4.1 Pressure Burst Test

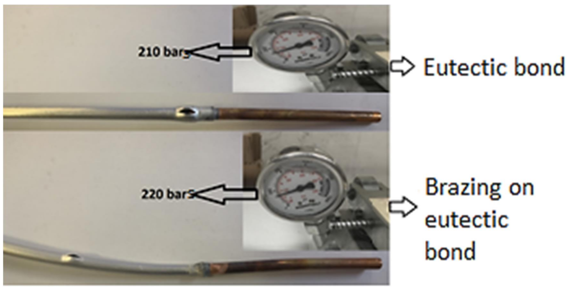

Figure 12. Explosion test result sample images and burst values.

The pressure burst test was carried out according to the ASTM f1387-99 standard. Average pressure test results and burst points are shown in Figure 12. According to these data, the sample to which the eutectic connection was made exploded from the aluminum pipe body point at 210 bar, and the brazing application on the eutectic exploded from the aluminum pipe body, not from the connection point at an average pressure of 220 bar. It has been observed that the specimens connected with the eutectic braze connection are more resistant to pressure by 4.76% compared to the eutectic joint.

2.2.4.2 Tensile Test

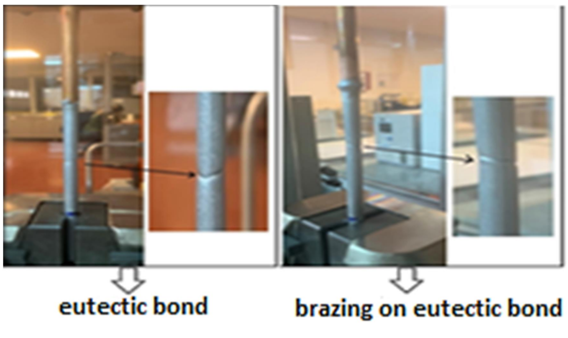

Figure 13. Breaking damage of samples in tensile test.

The samples for the tensile test were prepared according to the TS EN ISO 6892-1 standard. Figure 13 shows the deformation and rupture points that occur as a result of the tensile test applied to the samples. Ten samples were tested at a tensile test rate of 10 mm/min. In the data obtained from the tensile test device, the maximum shear force in the average eutectic connection was measured as 1108.59 N, and the average maximum shear stress amount was measured as 22.33 N/mm². The average maximum shear force measured in the test performed on the brazing application on the eutectic joint was 1257.66 N, and the average maximum shear stress amount was measured as 25.75 N/mm². In all tensile tests, all sample types were broken by the aluminum tube, not the connection point.

2.2.4.3 Leakage Test

Figure 14. Connecting the samples to the leak tester.

The samples given in Figures 9 and 11 were connected to the leak test device shown in Figure 14. A total of 400 samples were tested, 200 of each of both types. One end of the samples was connected to the device and the other end was closed with clamps in order to blind them to complete the test. As soon as the lid of the test device is closed, the device automatically presses 10 bar helium gas into the samples. Samples were tested for 60 seconds at 10 bar helium gas pressure. Leakage tests of the samples were carried out according to the TS EN ISO 2048 standard.

The device checks whether there is helium gas emission to the environment with helium gas detectors in the closed cabin during the test period. The device gives an audible warning in case of leakage in the materials and lights up the red warning lamp on it. If there is no leakage, it indicates that there is no leakage in the materials by turning on the green warning lamp. In the tightness test, 2 (1%) leaks were detected from the eutectic connected samples. It was determined that there was no leakage (0%) from the sample that was brazed on the eutectic.

2.2.4.4 Investigation of Microstructures

In order to examine the microstructure of the adhesion surfaces at the connection interfaces of the test specimens, sections were taken from the connection points of the specimens and examined under scanning electron microscopy (SEM). In order to examine the microstructures, all the connected samples were cross-sectioned with a circular saw before the connection area to examine the internal structure of the connection, then the samples were prepared by reducing them to a length of 15 mm.

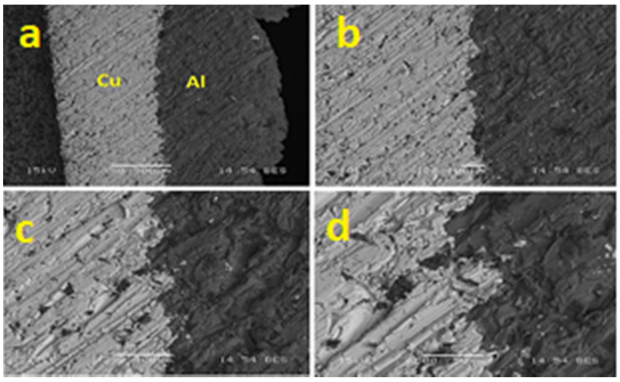

Figure 15. Microstructures of eutectic bond.

In Figure 15, microstructure images of the cross-sectional surface of the eutectic junction are given. The copper and aluminum sides are indicated in the images. The connection area and line are clearly visible in a and b views. In b and c images the dissolution of aluminum and copper in each other are shown. When SEM images are examined, aluminum and copper structures that melt into each other are seen. These structures are formed during coalescence when the eutectic temperature is reached.

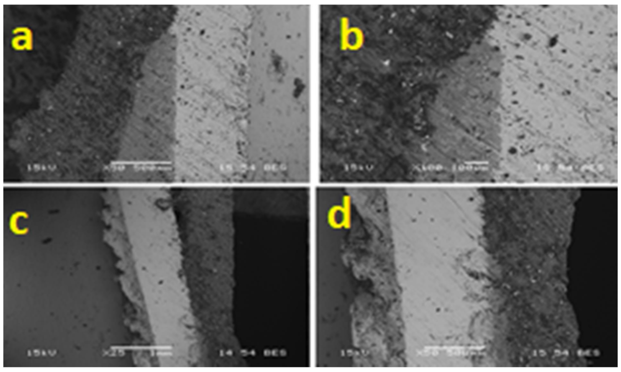

Figure 16. Microstructure images of braze bond on eutectic.

In Figure 16, the microstructure images of the brazed joints on the eutectic connection are given. Aluminum, copper, eutectic connection and braze filling regions are seen in the connection images of the microstructures. In images a and b, it can be seen that the brazing filler material is filled between the aluminum and copper. Images c and d show the eutectic bond and brazing filler together. The interfaces and boundary lines of the connecting regions are observed. Images of the filler metal on the surface held by the eutectic connection from the copper tube shrinkage point are observed. It has been observed that braze filler metal is located on the surfaces that the eutectic connection cannot fill. The gaps where the eutectic connection does not take place are filled with filler metal. Except for the eutectic joint gaps filled with filler, it was observed that the braze filler applied on the eutectic joint was homogeneously distributed and a second layer of protection was provided.

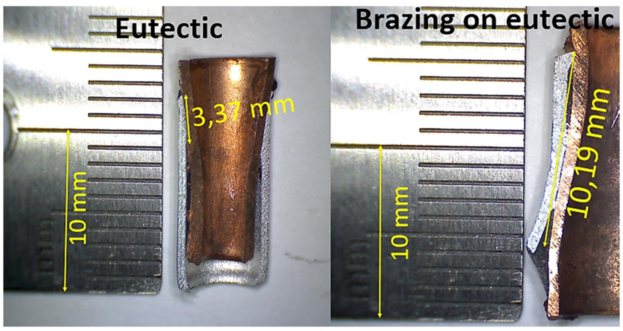

Figure 17. Connection lengths of samples.

As given in Figure 17, in the measurements made on the sample connection surfaces with the camera microscope, the connection length of the eutectic bonded aluminum and copper pipe was

3.37 mm, and the aluminum-copper connection length on which the eutectic was brazed was 10.19 mm.

3. Results

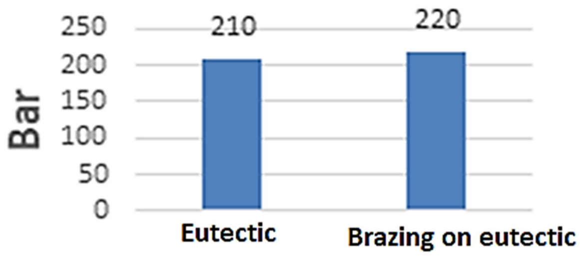

Figure 18. Burst test average results.

When the blast test results given in Figure 18 are evaluated, it has been seen that the test results of the eutectic and braze-on-eutectic test results are close to each other. When the blast zones were examined, it was observed that eutectic and eutectic samples were brazed on the eutectic, and the blast points occurred from the regions close to the aluminum tube body midpoints. According to these values, 4.76% better results were obtained from brazing onto eutectic than from eutectic connection.

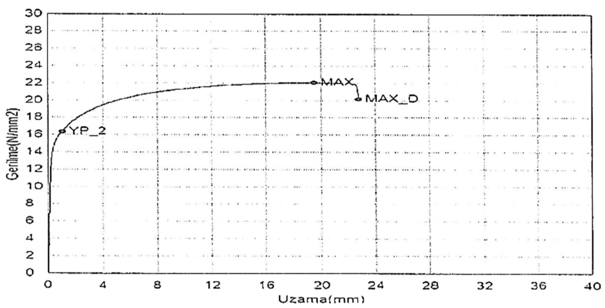

Figure 19. Eutectic junction stress-strain plot.

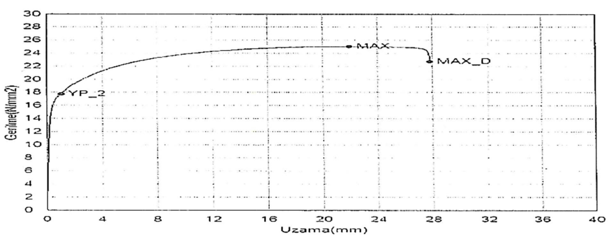

Figure 20. Brazing stress-strain plot over eutectic.

According to the tensile test results given in Figures 19 and 20, the average maximum shear stresses were obtained as 22.33 N/mm² for eutectic joint and 25.75 N/mm² for braze-on-eutectic joint. Both types of samples did not break from the connection area, they were completely broken from the aluminum pipe. According to these values, approximately 14.34% higher results were obtained from the brazing-on-eutectic connection compared to the other connection.

As it can be seen in Table 6, 2 (1%) leaky samples, ie leaky samples, were detected among 200 samples tested, each with eutectic connection. No leaks were detected (0%) in the tightness test of the specimens with brazed connection on the eutectic. It is thought that the gaps that may occur in the eutectic connection are filled with brazing filler, thus preventing sealing.

Table 6. Sealing test results.

Feature	Eutectic	Braze On Eutectic
Number of Tests	200	200
Number of Leaks	2	0
Leakage Percentage	%1	%0

Sections were taken from the samples that did not leak from the tightness test and examined under a scanning electron microscope.

When the connection points of the eutectic connected sample were examined under the microscope, it was seen that aluminum and copper dissolved in each other and formed a bond at the junction boundary line. The bond surface is between the angled surface of the copper tube and the surface where the aluminum contacts this point.

When the connection points of the sample on which brazing is applied on the eutectic bond are examined under the microscope, a eutectic bond that dissolves in each other is formed between the angled surface of the copper pipe and the aluminum in contact. In addition, the observation of the molten filler metal between the eutectic structures serves as a second protection layer for sealing by filling the gaps formed during the eutectic bond by the brazing filler, completing the connection as a whole.

Table 7. Bond lengths of the samples.

Feature	Eutectic	Braze On Eutectic
Bond Length	3.37 mm	10.19 mm

In Table 7, the bond lengths of the connections measured under a microscope with a camera are given. According to the results obtained, the longest connection line was obtained by brazing on eutectic with a length of 10.19 mm.

4. Conclusions

• Burst test results were close for ETC (Eutectic joint) and BETC (Brazing on eutectic joint).

• According to the tensile test results, 13,33% higher results were obtained from the BETC connection in shear stresses compared to the other connection.

• When we examine the leak test results, the leakage rate in BETC samples was completely eliminated in the test study with 200 samples each. It has been determined that there is a 1% leakage in the ETC.

• When we examined the connection points under the scanning electron microscope, it was seen that ÖTSL filled all the gaps and formed a longer connection line than ETC. It has been shown that filling all the gaps and interfaces gives better results in terms of sealing.

• With BETC connection, a connection length of 202.37% longer than ETC was obtained. In this case, it is thought that the samples produced with BETC can give longer-lasting and durable responses to vibrations in the system.

5. References

Ambroziak, A., Lange, A., Białucki, P., Derlukiewicz, W., & Szymczak, E., 2020. Comparison of properties of Al-Cu soldered and resistance welded joints. *Welding Technology Review*, **92**(2), 25-32.

Jung, D. H., Rajendran, S. H., & Jung, J. P., 2018. Effect of ZrO2 Nanomaterials on Wettability and Interfacial Characteristics of Al-19Cu-11Si-2Sn Filler Metal for Low Temperature Al to Cu Dissimilar Brazing. *Nanomaterials*, **8**(10), 784

Khalil Hazawi, A. R., Abdel-Magied, R. K., & Elsheikh, M. N., 2017. An experimental analysis of a flaring process for tube ends using a novel spinning tool. *The International Journal of Advanced Manufacturing Technology*, **92**(1), 157-165.

.Nazari Tiji, S. A., Asgari, A., Gholipour, H., & Djavanroodi, F., 2018. Modeling of equal channel forward extrusion force using response surface approach. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, **232**(4), 713-719.

Oğuz B., 1988. Sert Lehimleme Teknikleri. *Oerlikon Yayını.*

Shalaeva, M., & Loginov, Y., 2021. Influence of Recrystallization Annealing Modes on the Mechanical Properties of Copper Pipes After Large Plastic Deformation. *In MATEC Web of Conferences*, 346, EDP Sciences.

Takehiko, W., & Hiyasa, S., 1998. Eutectic bonding of Al pipe to Cu pipe. *Journal of the Japan Welding Society*, **16**(1), 35-44.

Yilmaz, N. F., & Öztürk, M., 2012. Improvement of mechanical properties of AA1070 aluminium by the addition of borax under different holding conditions. *Materialwissenschaft und Werkstofftechnik*, **43**(12), 1006-1018.

Yue, Z., Li, H., Taili, S., Qidong, L., & Xichuan, Z. (2011). Automatic control system of copper pipe and aluminum pipe butt resistance welding machine. *Procedia Engineering*, **15**, 613-617.