e-ISSN: 2667-4165 • **CİLT** / VOLUME: V • **SAYI** / ISSUE: II • **ARALIK** / DECEMBER 2022

AFYON KOCATEPE ÜNİVERSİTESİ ULUSLARARASI MÜHENDİSLİK TEKNOLOJİLERİ VE UYGULAMALI BİLİMLER DERGİSİ

Afyon Kocatepe University International Journal of Engineering Technology and Applied Sciences

www.dergipark.org.tr/tr/pub/akuumubd

AFYON KOCATEPE ÜNİVERSİTESİ
ULUSLARARASI MÜHENDİSLİK TEKNOLOJİLERİ ve UYGULAMALI BİLİMLER DERGİSİ
Afyon Kocatepe University
International Journal of Engineering Technology and Applied Sciences

Afyon Kocatepe University International Journal of Engineering Technology and Applied Sciences

http://dergipark.org.tr/akuumubd

e-ISSN:2667-4165

Afyon Kocatepe University
International Journal of Engineering Technology and Applied Sciences (AKU-IJETAS)

Volume: V / Number: 2 / December - 2022

Owner / Publisher: Prof. Dr. Ayhan EROL for Afyon Kocatepe University

Editor in Chief Prof. Dr. Ayhan EROL

Co- Editor in Chief Prof. Dr. Rıdvan ÜNAL

Published Afyon Kocatepe University, December 2022,

ijetas@aku.edu.tr

CONTACT INFORMATION

Afyon Kocatepe University International Journal of Engineering Technology and Applied Science Afyon Kocatepe University, Technology Faculty, 03200 Afyonkarahisar, TURKEY

Phone: +90-272-2281446 /ext.

Fax: +90-272 228 1449

e-mail : ijetas@aku.edu.tr, aerol@aku.edu.tr

Welcome to AKU-IJETAS

Dear Researchers;

Afyon Kocatepe University International Journal of Engineering and Applied Sciences ler has been published in Turkish and English since 2018 with 2 issues. Our journal will accept Turkish and English articles as 2 issues a year and the articles will be evaluated by at least two referees with the same system. Our magazine from December 2018; it offers many advantages to readers due to the practical and practical access to the authors as well as the process of publishing and publishing quickly and easily; The electronic journal (e-ISSN:2667-4165) accepts 2 numbers per year (June and December) in Turkish and English. The names of the judges evaluating the articles are not notified to the authors. The referees cannot see the names of the authors. The studies are evaluated as at least two referees. Our authors, who want to send articles, can register their original scientific articles online and follow the process by registering on our magazine page. Our journal is accepted as original and previously published research articles.

We are waiting for your contributions as both referee and writer. I thank you in advance for your support and I wish you success in your work.

Prof. Dr Ayhan EROL

Chief Editor

Danışma Kurulu / Editörler/ Editorial Board

CONTENTS

Page

Afyon Kocatepe Üniversitesi Uluslararası Mühendislik Teknolojileri ve Uygulamalı Bilimler Dergisi

Afyon Kocatepe University International Journal of Engineering Technology and Applied Sciences

AKÜ IJETAS Cilt **5(2)** (2022) Aralık (18-26 s) AKU J.Eng.App.Sci. Vol **5(2)** (2022) December (18-26 pp)

DOI:10.373123/akuijetas.1148677

Araştırma Makalesi / Research Article

e-ISSN 2667-4165 (https://dergipark.org.tr/akuumubd

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

Received:25.07.2022 ; Accepted:23.09.2022

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

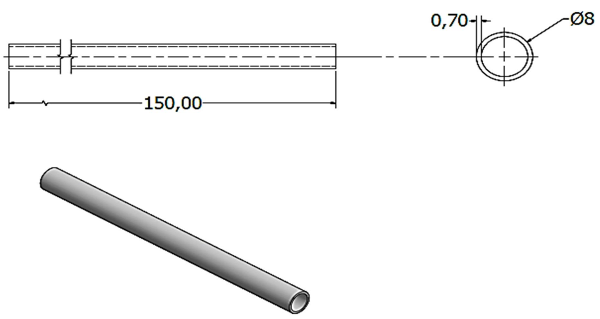


Figure 1. Flat end aluminum tube dimensions.

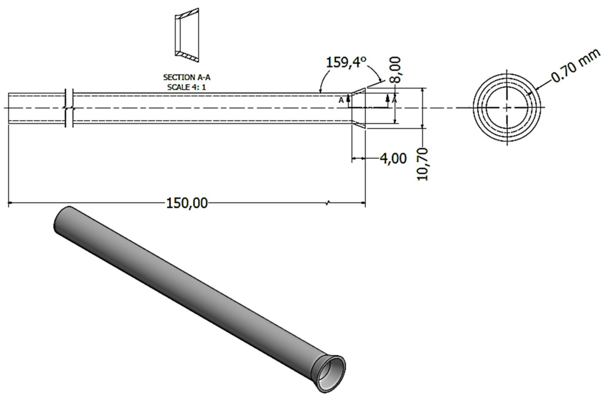


Figure 2. Flared end aluminum tube dimensions.

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

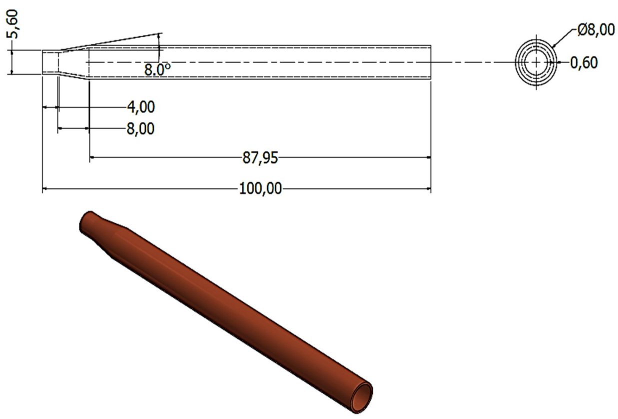


Figure 3. End shrink treated copper pipe dimensions.

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

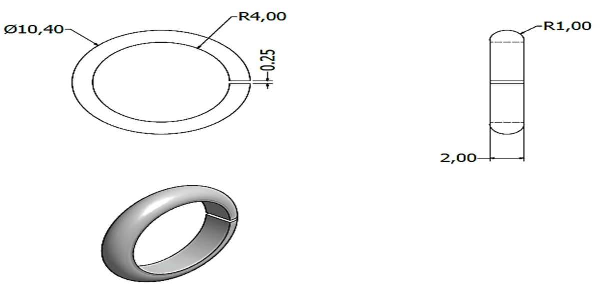


Figure 4. Dimensions of A5.8-BAlSi-4 brazing filler material.

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).

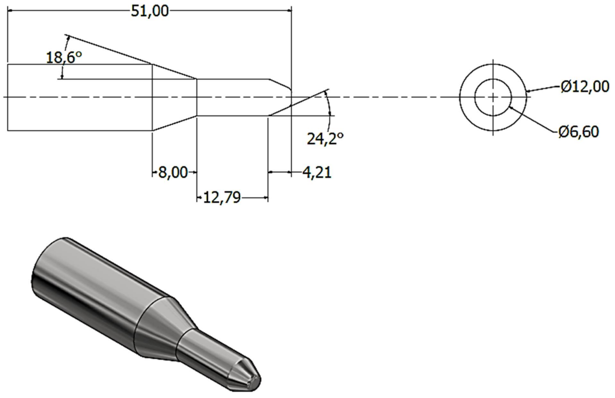


Figure 6. Brazing application punch on the eutectic junction.

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).

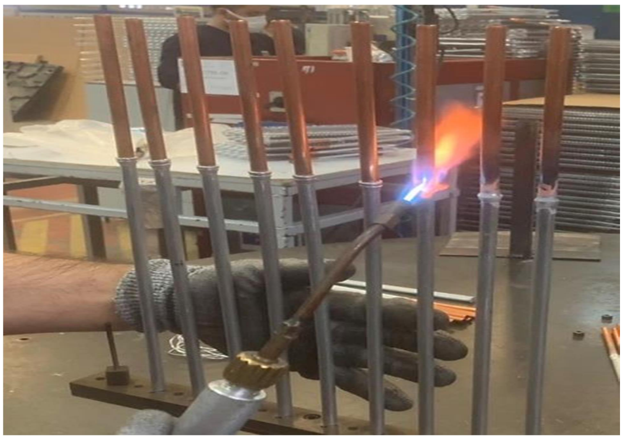


Figure 7. Applying brazing on the eutectic junction.

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

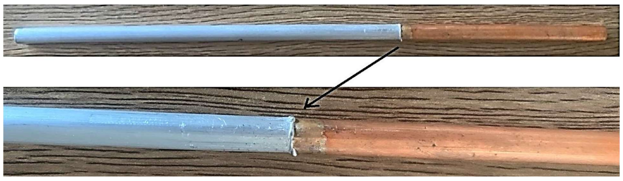


Figure 8. Image of aluminum-copper pipe eutectic connection.

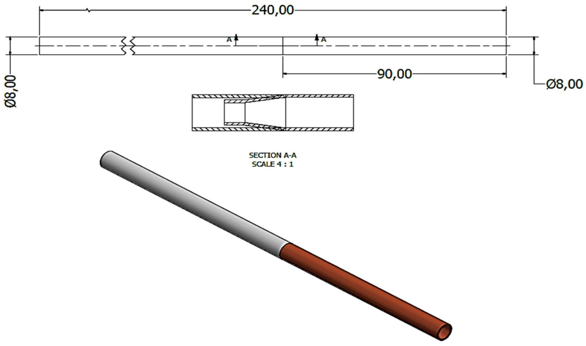


Figure 9. Dimensions of aluminum and copper pipe with eutectic connection.

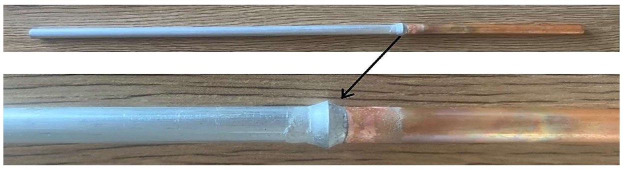


Figure 10. Image of brazing application on eutectic connection of flared aluminum-copper tube.

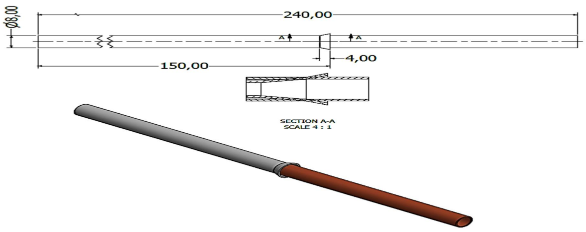


Figure 11. Dimensions of flared aluminum and copper pipe with brazed on the eutectic joint.

2.2.4 Tests and Reviews

2.2.4.1 Pressure Burst Test

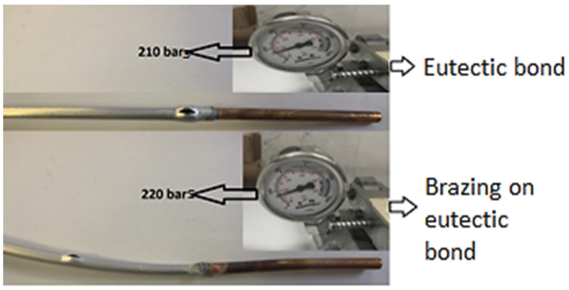


Figure 12. Explosion test result sample images and burst values.

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

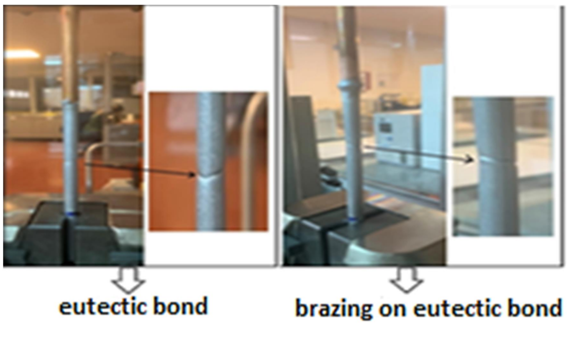


Figure 13. Breaking damage of samples in tensile test.

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.

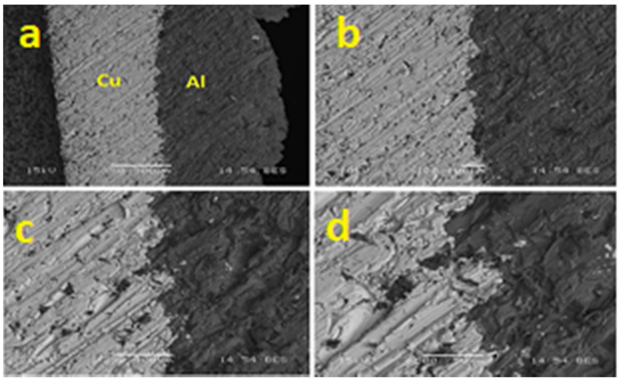


Figure 15. Microstructures of eutectic bond.

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.

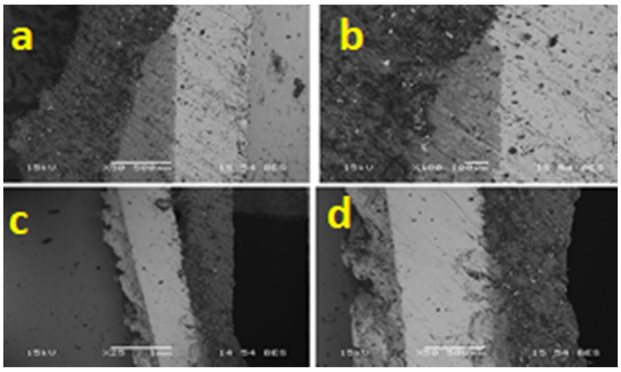


Figure 16. Microstructure images of braze bond on eutectic.

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.

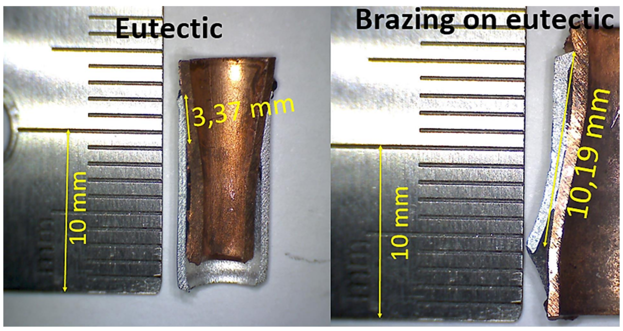


Figure 17. Connection lengths of samples.

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

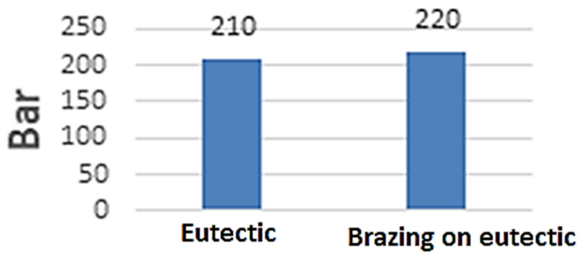


Figure 18. Burst test average results.

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.

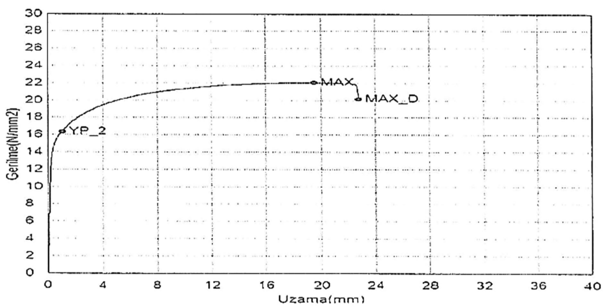


Figure 19. Eutectic junction stress-strain plot.

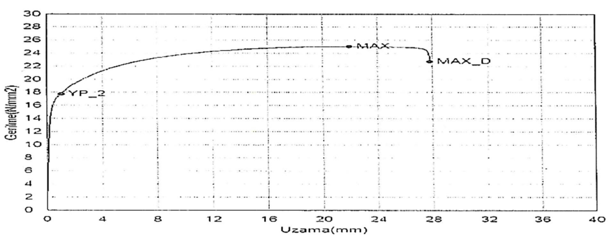


Figure 20. Brazing stress-strain plot over eutectic.

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.

Afyon Kocatepe Üniversitesi Uluslararası Mühendislik Teknolojileri ve Uygulamalı Bilimler Dergisi

Afyon Kocatepe University International Journal of Engineering Technology and Applied Sciences

AKÜ IJETAS Cilt **5(2)** (2022) Aralık (27-31 s) AKU J.Eng.App.Sci. **Vol 5(2)** (2022) December (27-31 pp)
DOI:10.53448/akuumubd.1214679

Araştırma Makalesi / Research Article
e-ISSN 2667-4165 (https://dergipark.org.tr/akuumubd

DA Motor Kontrolünde Gürültünün Sistem Performansına Olan Etkisi

Ahmet Akbulut
[1]Ankara University,Engineering Faculty, Department of Electric-Electronic Engineering , Ankara, Turkey.

e-posta: aakbulut@ankara.edu.tr. ORCID ID://orcid.org/0000-0001-8868-7385

Geliş Tarihi:05.12.2022 ; Kabul Tarihi:14.12.2022

Anahtar kelimeler
Parçacık Sürü Optimizasyonu; Ziegler-Nichols; PID kontrol; DA Motor.

Öz

DA motor endüstride ve günlük yaşantıda en çok kullanılan elektrik motorlarındandır. Bu tip motorların hız ve konum kontrolü özellikle hassas üretim, güvenli haraket sağlanması ve verimlilik bakımından önem taşımaktadır. PID, DA motor kontrolünde en sık kullanılan kontrol yöntemlerinden birisidir. Bu çalışmada gerçek DA motor parametreleri üzerinden, Parçacık Sürü Optimizasyonu algoritması ve Ziegler-Nichols yöntemi kullanarak DA motor hız kontrolünde PID kontrolcü katsayıları belirlenmiş ve bu iki yöntemin karşılaştırması yapılmıştır. Çalışmada çıkış sinyaline gürültü eklenmiş, gerçek sistem değerlerine yakın çıkış değerleri elde edilmiştir. Böylelikle test sonuçlarının gerçeğe daha yakın bulunması amaçlanmıştır.

The Effect of Noise on System Performance in DC Motor Control

Keywords
Particle Swarm Optimization; Ziegler-Nichols; PID control; DC Motor.

Abstract

DC motor is one of the most used electric motors in industry and daily life. The speed and position control of this type of motor is especially important in terms of precision production, safe movement and efficiency. PID is one of the most commonly used control methods in DC motor control. In this study, PID controller coefficients were determined in DC motor speed control by using Particle Swarm Optimization algorithm and Ziegler-Nichols method over real DC motor parameters and these two methods were compared. In the study, noise was added to the output signal, and output values close to the real system values were obtained. Thus, it was possible to obtain test results that can approximately represent real conditions.

1. Giriş

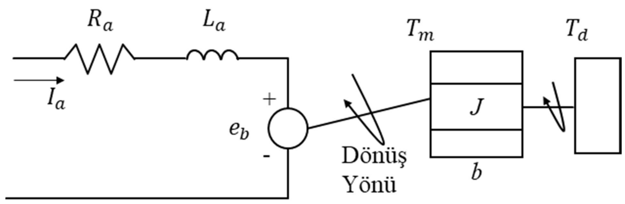
Elektrik motorları arasında en çok tercih edilenlerden birisi DA motorlardır. Kullanım alanının oldukça fazla ve çeşitli olması, bu motorların yer aldığı uygulamaların sayısını oldukça arttırmıştır. Bu uygulamalar arasında en çok DA motorun hız ve konum kontrolü yer tutmaktadır. Bu amaçla birçok kontrol sistemi geliştirilmiş, bu sistemlerin optimizasyonu için çok çeşitli algoritmalar uygulanmış ve test edilmiştir. En çok kullanılan kontrol yöntemlerinden birisi PID kontroldür. Klasik ve uyarlanmış PID kontrol endüstriyel kontrolcülerin yarısından fazlasında kullanılmaktadır. Bunun nedeni PID kontrolcülerin ayarlanabilirlik açısından kolaylık sağlamasıdır. Parametreleri ayarlayamak için çok çeşitli yöntemler kullanılabilir (Ogata 2010). PID kontrolde kontrol katsayılarının belirlenmesi büyük önem taşımaktadır. Gökçe vd. (2022) yaptıkları çalışmada, kontrol katsayılarını belirlemek için PSO algoritması ve ZN yöntemlerini uygulamış ve sonuçlarını karşılaştırmıştır. Basamak referans ve basamak yük, sinüsoidal referans ve sinüsoidal yük altında sistemi test etmiştir. Sinüsoidal referans ve yük altında, farklı yük frekansları uygulamış, PSO ve ZN yöntemlerinin katsayı belirlemedeki performanslarını karşılaştırmıştır. Çalışma sonucunda PSO algoritmasının daha iyi bir sonuç verdiği gözlemlenmiştir. Idir vd. (2018) yaptıkları çalışmada optimizasyon tekniklerine dayalı bir Kesirli-Dereceli PID kontrolör tasarlamıştır. Katsayıları ayarlamak için Diferansiyel Evrim ve Parçacık Sürü Optimizasyonu (PSO) algoritmalarını kullanmış ve sonuçlarını karşılaştırmıştır. Hasan ve Rashad (2019) yaptıkları çalışmada sabit mıknatıslı DC motor için Kesirli-Dereceli PID kontrolör tasarlamış ve parametreleri ayarlamak için PSO algoritması kullanmıştır. Çalışma Simulink üzerinde deneysel olarak gerçekleştirilmiştir. Dış bozucuların etkisi altında referans takibi ve sistem sağlamlığı konusunda sonuçlar paylaşılmıştır. Yazgan vd. (2019) yaptıkları çalışmada PSO, Genetik Algoritma (GA) ve Ziegler-Nichols (ZN) yöntemini DC motor hız kontrolünde PID parametrelerini ayarlamak için uygulamıştır. Yöntemler beş kriter altında değerlendirilmiş ve PSO algoritmasının diğerlerinden daha iyi bir performans ortaya koyduğu gösterilmiştir. Ma'arif vd. (2022) yaptıkları çalışmada PID parametrelerinin optimizasyonu için Simulink üzerinde PSO algoritması kullanmış ve optimum parametre değerlerini elde etmiştir. Daha sonra arduino üzerinde kurdukları sistemde bu parametreleri kullanmış, yükselme süresi ve yerleşme süresi açısından sonuçları gözlemlemiş ve değerlendirmiştir. DA motorlar günümüzde kuadkopter gibi multikopterler, robotik gibi geniş kullanım alanına sahip sistemlerin temel parçasıdır. Bu nedenle kuadkopterlerin stabil uçuşları, robotların hareket ve dönüş kabiliyetlerinin durumu önemli ölçüde kontrol sistemine bağlıdır. Gökçe vd. (2021) yaptıkları çalışmada tarımda kullanılmak üzere hazırlanan dört tekerli bir robotun kinematik ve sistematik analizini gerçekleştirmek için matematiksel model oluşturmuştur. Kontrol için PID kontrolcü kullanılmış ve parametreleri optimize etmek için PSO algoritması kullanılmıştır. Bu çalışmada çıkış sinyaline Gauss gürültüsü eklenmiş ve PID parametrelerini belirlerken kullanılan hata verisinin gürültülü sinyal üzerinden hesaplanması sağlanmıştır. Ayrıca sistemin çıkış sinyaline gürültü eklenerek sonuçlar gözlenmiştir.

2. Materyal ve Metot

Çalışmada DA motor parametreleri olarak gerçek değerler kullanılmıştır (IntKyn. 1).

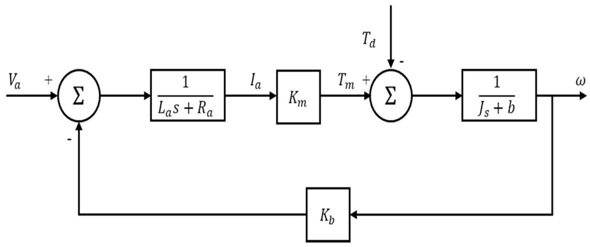
2.1 DA Motor

endüstriyel sistemler ve gündelik hayatta sıklıkla kullanılan DC motorlar, bir doğru akım elektrik kaynağından beslenen elektrik motorlarıdır.



Şekil 1 DA Motor Elektriksel Modeli

Şekil 1'de DA motorun elektriksel modeli gösterilmiştir. Elektriksel devrenin analizi sonucunda elde edilen kontrol algoritmasının blok şeması Şekil 2'de verilmiştir.



Şekil 2 DA Motor Blok Şeması

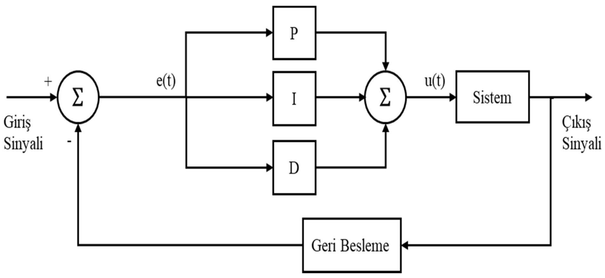
Bu çalışma bağlamında ölçülen hıza gürültü eklenmiş ve kontrolöre o şekilde girilmiştir.

$w_{ölçülen}$=w+gürültü

Ayrıca dış bozucu sinüsoidaldir. Yük frekansından kasıt bu sinüsoidal dış bozucunun frekansıdır.

2.2 PID Kontrol

Sistemlerin giriş ve çıkış durumlarını kontrol eden sistemlere kontrol sistemi denir. Kontrol sistemlerinden en önemli parametrelerden birisi geri besleme sinyalidir. Geri besleme sinyali ile giriş ve çıkış değerleri arasındaki fark alınır ve oluşturulan kontrol algoritmaları bu farkı değerlendirerek parametreleri belirler.

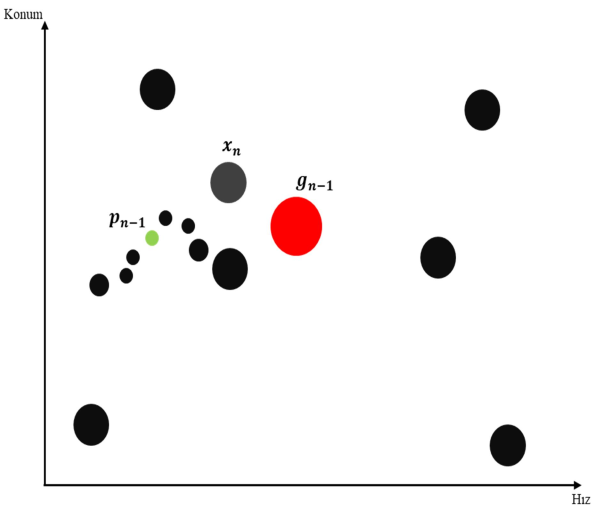


Şekil 3 PID Kontrol Blok Şeması

Şekil 3'te PID kontrol sistemi için blok şeması gösterilmiştir. Doğada, toplu hareket ederken zeki davranışlar sergileyen canlılar vardır. Bu sürüye ait bireyler sadece kendi tecrübeleri değil sürüdeki diğer bireylerinde tecrübelerinden yararlanarak problemler karşısında çözümler üretmektedir. (Akyol ve Alataş 2012).

2.3 Parçacık Sürü Optimizasyonu

PSO, sürü halinde hareket eden hayvan türlerinin yemek, su gibi temel ihtiyaçlarını ararken sergiledikleri davranıştan etkilenerek ortaya atılmıştır.



Şekil 4 PSO Çalışma Mekanizması (Gökçe vd. 2022).

Her parçacığın bir hızı vardır. Bu hız anlık konum ve bir sonraki konumu belirler. Her adımda parçacığın anlık hızı ve bir önceki adımda hesaplanan hızı toplanarak yeni konum elde edilir.

$$x_n = x_{n-1} + v_n \quad (1)$$

x_n : Parçacık konumu

v_n : Parçacık hızı

$$v_n = c_1 v_{n-1} + c_2(x_{n-1} - p_{n-1}) + c_3(x_{n-1} - g_{n-1} \quad (2)$$

Parçacık Momentumu (son adımdaki hızı): v_{n-1}

Parçacığın anlık bulduğu en iyi noktanın konumu: p_{n-1}

Tüm parçacıkların anlık bulduğu en iyi noktanın konumu g_{n-1}

Parçacığın yeni hızı, c_1, c_2, c_3 belirli katsayılar olmak üzere eşitlik (2) ile hesaplanır.

2.4 Ziegler-Nichols Yöntemi

"Yöntemde integral zaman sabiti ve türev zaman sabiti sıfırlanır. Kontrol edici kazancı (K_c) sistem çıkışı sürekli salınım yapana kadar arttırılır. Sürekli salınım gözlendiğinde salınım periyodu (T_u) ve kontrol edici son kazancı (K_u) kaydedilir. Kaydedilen bu değerlerden yararlanılarak, Ziegler-Nichols metodunda kullanılan tablodan kullanılacak kontrolör için değerler belirlenir." (Durusu, 2022).

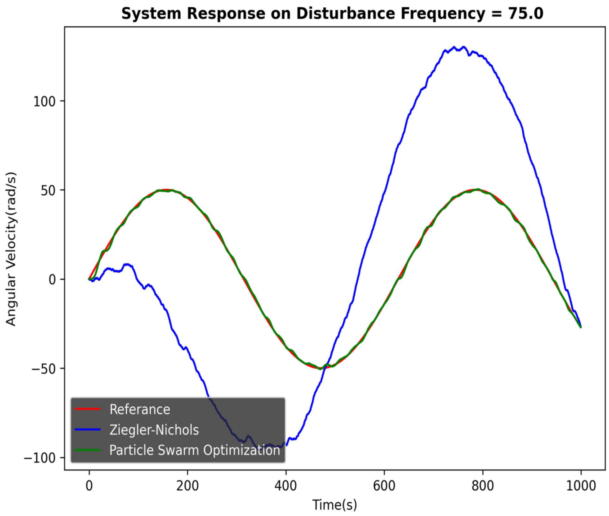
Çizelge 1 Ziegler-Nichols Metodu Tablosu (Ziegler ve Nichols 1993)

Kontrol Tipi	K_p	T_i	T_d	K_i	K_d
P	0.5 K_u	-	-	-	-
PI	0.45 K_u	0.80 T_u		$0.54 K_u/$	-
PD	0.8 K_u	-	$0.125 T$	-	$0.10 K_u T$
PID	0.6 K_u	0.5 T_u	$0.125 T$	$1.2 K_u/T$	$0.075 K_u$

Çizelge 1'de ZN yönteminde PID katsayılarını belirlemek için kullanılan tablo verilmiştir. Kullanılan yöntemlerin karşılaştırılması sonucu elde edilen bulgular Bölüm 3'te paylaşılmıştır.

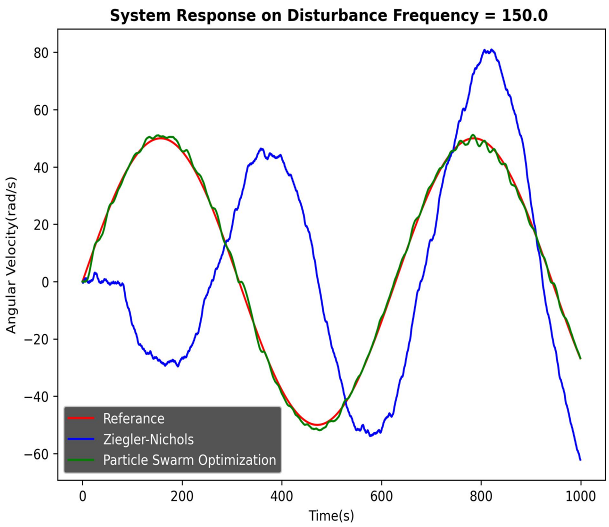
3. Bulgular

Farklı frekansa sahip yükler altında sistem test edilmiş ve Şekil (5-7)'de sistem çıktıları gösterilmiştir.



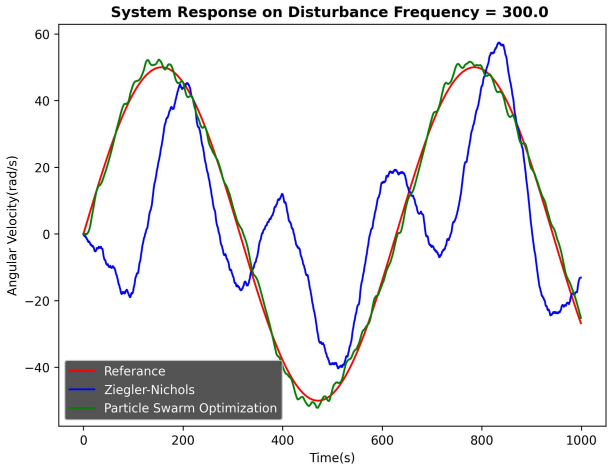
Şekil 5 75 Hz yük altında sistem tepkisi

Şekil 5'te görüldüğü üzere PSO algoritması referans takibi konusunda ZN yönteminden çok daha üstün bir performans sergilemiştir.



Şekil 6 150 Hz yük altında sistem tepkisi

Şekil 6'da görüldüğü üzere yük frekansı iki katına çıkarılmış ve sistem test edilmiş ve yine PSO algoritmasının çok daha üstün performans sergilediği gözlemlenmiştir.



Şekil 7 300 Hz yük altında sistem tepkisi

Şekil 7'de görüldüğü üzere sistem tepkisi yine belirtilen frekansa sahip yük altında çok daha üstün performans sergilemiştir.

4. Tartışma ve Sonuç

DA motorun hız kontrolü için kullanılan PID kontrol sisteminin parametrelerini belirlemek için PSO ve ZN yöntemleri kullanılmış ve karşılaştırmaları yapılmıştır. Bölüm 1'de belirtildiği gibi Gökçe vd. (2022) yaptıkları çalışmada yöntem sonucu elde edilen çıkış sinyallerini ideal şartlar kabul ederek oluşturmuştur. Bu çalışmada sistem tepkisine gerçek verilere daha yaklaşık değerler elde edebilmek için Gauss gürültüsü eklenmiştir. Elde edilen sonuçlar, bahsedilen çalışmalarda olduğu gibi yine PSO algoritmasının ZN yöntemine göre çok daha iyi bir performans sergilediğini ortaya koymuştur. Elde edilen veriler, sistemin gerçek zamanlı uygulamasının yapılarak deney sonuçları ile karşılaştırılmasına da imkan sağlamaktadır.

5. Kaynaklar

Akyol, S., Alataş, B., 2012. Güncel Sürü Zekası Optamizasyon Algoritmaları. *Nevşehir Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 1,* ***1,*** *36-50.*

Durusu, V., 2022, PSO ve ZN Metodunu Kullanarak DC Motorun Hız Kontrolü için PID Parametrelerinin Belirlenmesi ve Karşılaştırılması. Yüksek Lisans Tezi, Afyon Kocatepe Üniversitesi Fen Bilimleri Enstitüsü, Afyonkarahisar, 85.

Gökçe, B., Koca, Y.B., Aslan, Y., Gökçe, C.O., 2021, Particle swarm optimization-based optimal PID control of an agricultural mobile robot. *Comptes rendus de l'Académie bulgare des Sciences*, 74, **4**, 568-575.

Gökçe, C. O., Durusu, V., Unal, R. (2022). Farklı Yük Çeşitleri için Parçacık Sürü Optimizasyonu ve Ziegler-Nichols Metodunun DC Motor Hız Kontrolü Probleminde Karşılaştırılması. *Avrupa Bilim ve Teknoloji Dergisi*, **33**, 88-92.

Hasan, F.A., Rashad, L.J., 2019, Fractional-order PID controller for permanent magnet DC motor based on PSO algorithm. *International Journal of Power Electronics and Drive System,* 10, **4**, 1724-1733.

Idir, A., Kidouche, M., Bensafia, Y., Khettab, K., Tadjer, S.A., 2018, Speed Control of DC Motor Using PID and FOPID Controllers Based on Differential Evolution and PSO. *International Journal of Intelligent Engineering & Systems,* 11, **4**, 241-249.

Ma'arif, A., Rahayu, E.S., Çakan, A., Particle Swarm Optimization (PSO) Tuning of PID Control on DC Motor. *International Journal of Robotics and Control Systems,* 2, **2**, 435-447.

Nasri, M., Nezamabadi-Pour, H., Maghfoori, M., 2007, A PSO-Based Optimum Design of PID Controller for a Linear Brushless DC Motor. *World Academy of Science, Engineering and Technology*, 26, **40**, 211-215.

Ogata, K., 2010. Modern Control Engineering Fifth Edition. Marcia J. Horton (editor), Pearson, 567-575.

Yazgan H., Yener F., Soysal S., Gür, A., 2019, Comparison Performances of PSO and GA to Tuning PID Controller for the DC Motor. *Sakarya University Journal of Science*, 23, **2**, 162-174.

Ziegler, J.G., Nichols, N.B., 1942, Optimum Settings for Automatic Controllers. *Transactions of the American Society of Mechanical Engineers,* 64, **11**, 759-765.

İnternet kaynakları

1-https://www.moog.com/content/dam/moog/literature/MCG/moc23series.pdf, (10.11.2022).
2-https://commons.princeton.edu/josephhenry/wp-content/uploads/sites/71/2019/08/electric-motor-history.pdf, (12.11.2022).
3-https://machinelearningmastery.com/a-gentle-introduction-to-particle-swarm-optimization/ (13.11.2022).

Afyon Kocatepe Üniversitesi Uluslararası Mühendislik Teknolojileri ve Uygulamalı Bilimler Dergisi

Afyon Kocatepe University International Journal of Engineering Technology and Applied Sciences

AKÜ IJETAS Cilt **5(2)** (2022) Aralık (32-39s) AKU J.Eng.App.Sci. **Vol 5(2)** (2022) December (32-39 pp)

Derleme Makalesi / Review Article

e-ISSN 2667-4165 (https://dergipark.org.tr/akuumubd

Cam Takviyeli Termoset Kompozit Atıkların Geri Dönüşüm Yöntemlerinin İncelenmesi

Miray Basar Macit[1], Ali Gursel[2]

[1]Düzce University, Institue of Science, Technology of Composite Material, Konuralp, Düzce,Turkey.

[2] Düzce University, Faculty of Engineering, Department of Mechatronic Engineering, Konuralp, Düzce, Turkey

e-mail: [1]mrymacit@gmail.com ORCID ID:0000-0002-1388-2781, [2] aligursel@duzce.edu.tr ORCID ID:0000-0002-5322-7941

The arrival date: 07.112022 Date of Acceptance:25.11.2022

Öz

Termoset reçine matrisli cam fiber takviyeli kompozitler istenilen mekanik özellikleri karşılamaları, hafiflikleri, korozyona karşı dirençli olmaları, kolay üretilebilirlikleri, esnek tasarım özellikleri ve çevresel etkilere karşı dayanıklı olmaları gibi avantajları nedeniyle tüm dünyada gün geçtikçe artan alan ve miktarlarda kullanılmaktadır. Termoset reçinelerin içerdikleri yoğun çapraz bağlar nedeniyle ısı ile yeniden şekillendirilmesi mümkün değildir. Bu özellikleri nedeniyle termoset reçine matrisli kompozit malzemeler kullanım ömürleri sonunda ekolojik ve çevresel açıdan sorun oluşturmaktadır. Bu çalışmada endüstride yaygın olarak kullanılan TsGFRP (Cam Elyaf Takviyeli Termoset Polimer) kompozit malzemelerin servis ömürlerini tamamladıklarında oluşan atıkların geri dönüşüm özellikleri incelenmiştir. Günümüzde farklı ihtiyaçların karşılanmasına yönelik çok farklı özelliklere sahip malzemeler tasarlanmakta ve büyük miktarlarda üretilmektedir. Bununla birlikte artan atık yükünün bertarafı konusunda sürdürülebilir çözümler üretilmesi vazgeçilmez bir gereklilik olarak karşımıza çıkmaktadır. TsGFRP kompozit malzemelerin geridönüşümü konusunda çeşitli çalışmalar yapılmıştır. Ancak bugüne kadar yapılan çalışmalar maliyet ve kazanım açısından değerlendirildiğinde etkin ve sürdürülebilir bir yöntem oluşturulabilmiş ve yaygın bir kullanım alanı sağlanabilmiş değildir. Bu bağlamda yeni araştırmalar yapılarak servis ömürlerini tamamlamış TsGFRP kompozit malzemelerin yeniden kullanımları ve geridönüşümlerine yönelik sürdürülebilir çözüm yöntemlerinin araştırılmasının öncelikli bir gereklilik olduğu anlaşılmıştır.

Anahtar Kelimeler
Ömrünü Tamamlamış Cam Elyaf Takviyeli Kompozit; Cam Elyaf Takviyeli Termoset Polimer; Geri Dönüşüm; Atık Bertarafı

An Investigation on Recycling of the Glass Fiber Reinforced Thermoset Composite Wastes

Abstract

Thermosetting resin matrix glass fiber reinforced composites are used in increasing areas and quantities all over the world due to their advantages such as meeting the desired mechanical properties, lightweight, resistant to corrosion, easy production, flexible design features, and resistant to environmental effects. However, it is not possible to reshape thermoset resins with heat due to the cross-linked networks. Due to these properties, composite materials with thermo-setting resin matrix cause ecological and environmental problems at the end of their life of usage. In this study, the recycling properties of end-of-life TsGFRP (Glass Fiber Reinforced Thermoset Polymer) composite waste materials, which are widely used in the industry were investigated. Today, materials with different properties are designed and produced in large quantities to meet advanced needs. However, it is an indispensable necessity to produce sustainable solutions for the disposal of the increasing waste load. Various studies have been carried out on the recycling of TsG-FRP composite materials. Unfortunately, the studies carried out so far, evaluated in terms of cost and gain, an effective and sustainable method has not been established and a widespread usage area has not been achieved. In this context, it has been understood that researching sustainable solution methods for the reuse and recycling of end-of-life TsGFRP comosite waste materials is a priority requirement in new studies

Keywords
End-of-life GFRP Composite; Glass Fiber Reinforced Thermoset Polymer; Recycling; Waste Treatment.

1. Introduction

GFRP1 Composite materials are design materials produced for achieving different properties and functionality. While fiber is used as a reinforcing element in these materials, thermosetting resins are used as matrix material in larger quantities than the reinforcing element in volume. Various fillers and dyestuffs can be added to the matrix according to the properties desired to be achieved in the designed material. The matrix also contains substances that require a chemical reaction. Glass fibers in the composite can exist in either a continuous or discontinuous phase (Demirel2008).

While glass fiber is used for increasing the mechanical strength in composite materials in general, matrix materials play an important role in increasing the corrosion resistance, distributing the incoming load and the integrity of the structure, while also playing an important role in determining the physical, chemical, thermal properties, and strength of the structure (Ianasi2020, Kaya2016)

GFRP composites can be produced with various production techniques that made them preferred for different purposes. Thanks to the wide advantages they provide, they are used in a very wide area and scale all over the world. The first use of glass-reinforced composites was seen in airplanes and boat hulls. Fiber Reinforced Composite materials first started with the use of aircraft and boat hulls in the field of transportation, and then with the development of different production techniques over time, the usage area has increased and continues to expand (IntKyn.1).

The size of the global composite market has reached 88.4 billion dollars as of 2019. Even though the composite market shrank to 74 billion dollars in 2020 due to the global economic crisis caused by the COVID-19 epidemic, it is estimated that the demand will revive and reach 112.8 billion dollars by 2025 with the recovery in the supply chains. Today, the Turkish composite material market has reached 1.5 billion Euros and a volume of 280,000 tons. The sector is growing in the range of 8-12% in Turkey, above the growth rate of Europe and the World (IntKyn.2).

Fiber Reinforced Composite materials are used all over the world in the fields of aviation, wind energy, consumer goods, marine, sports and entertainment equipment, transportation, defense industry, electrical electronics, pipes, tanks, and infrastructure. Fiber Reinforced Composite materials are used for many different purposes in the field of transportation due to their lightweight, superior resistance to water, corrosion, different weather conditions, and self-colouring abilities.

Construction and sub-sectors related to construction are the areas where fiber reinforced composite materials are used the most, due to their advantages such as strength/weight ratio, design flexibility, high resistance to weather conditions, and non-flammability. In the construction industry; It finds use in applications such as infrastructure (piping systems), structural parts, cladding panels, cladding panels (e.g. for prefabricated buildings), roofing tiles, pipes as well as bathroom furniture (e.g. bath and shower trays). Many decorative details such as columns and balustrades are carved from rigid foam, then coated with glass fiber and polyester resin, strengthened, and made resistant to weather conditions (IntKyn.1).

The size of the global composite market has reached 88.4 billion dollars as of 2019. Even though the composite market shrank to 74 billion dollars in 2020 due to the global economic crisis caused by the COVID-19 epidemic, it is estimated that the demand will revive and reach 112.8 billion dollars by 2025 with the recovery in the supply chains. Today, the Turkish composite material market has reached 1.5 billion Euros and a volume of 280,000 tons. The sector is growing in the range of 8-12% in

Turkey, above the growth rate of Europe and the World (IntKyn.2).

Fiber Reinforced Composite materials are used all over the world in the fields of aviation, wind energy, consumer goods, marine, sports and entertainment equipment, transportation, defense industry, electrical electronics, pipes, tanks, and infrastructure. Fiber Reinforced Composite materials are used for many different purposes in the field of transportation due to their lightweight, superior resistance to water, corrosion, different weather conditions, and self-colouring abilities.

Construction and sub-sectors related to construction are the areas where Fiber Reinforced Composite materials are used the most, due to their advantages such as strength/weight ratio, design flexibility, high resistance to weather conditions, and non-flammability. In the construction industry; It finds use in applications such as infrastructure (piping systems), structural parts, cladding panels, cladding panels (e.g. for prefabricated buildings), roofing tiles, pipes as well as bathroom furniture (e.g. bath and shower trays). Many decorative details such as columns and balustrades are carved from rigid foam, then coated with glass fiber and polyester resin, strengthened, and made resistant to weather conditions (IntKyn.1).

Fiber Reinforced Composite materials are preferred in many furniture and various household appliances, including water-contact dishwashers and washing machines, due to their light strength, very good waterproofing, and electrical and thermal properties.

Fiber Reinforced Composite materials are preferred in many furniture and various household appliances, including water-contact dishwashers and washing machines, due to their light strength, very good waterproofing, and electrical and thermal properties.

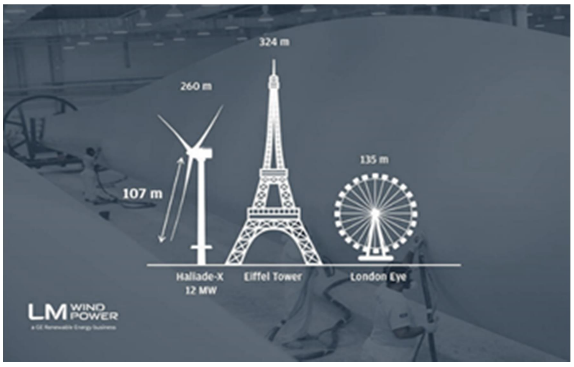


Figure 1. GE Haliade-X Wind Turbine (IntKyn.2).

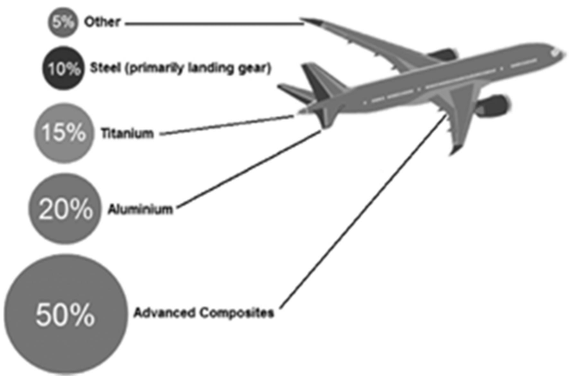


Figure 2. Materials of an airplane (IntKyn.2)

The benefits of GFRPs are listed below;

- Strength/weight ratio advantage and hardness,
- Easy and numerous production techniques, at low cost.
- Few production possibilities at low cost, (hand layup method) and unlimited moulding sizes
- Self colouring possibility and design flexibility and opportunity to harmonize with other materials
- Resistance to water, many chemicals, weather conditions, UV rays
- Good electrical and thermal properties
- Possibility of producing materials in different layers and in different combinations to obtain different mechanical properties
- In the volumetric phase, less energy is needed for the production of GRP than metals (Demirel2008).

Despite all advantages of GFRP composites, which are increasingly used in very large areas, end-of-life composite wastes pose a problem. With the developing technology, the increasing production amount of GFRP composite materials that meet different needs in the industry also causes a great increase in the waste load.

The ecological problems caused by the depletion of natural resources and the increasing waste load increase the importance of developing sustainable waste management solutions all over the World Commission on Environment and Development, published "Our Common Future Report", in April 1987. Sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" on that report. Therefore, environmental protection requirements should be considered manufacture and design of materials and taking into account future generations. Adopting sustainable development to industrial production has become one of the greatest challenges of the century. For this reason, there has been an increasing global trend in waste disposal. Designing and production plans should be done by considering waste disposal and environmental effects (Ming et al. 2021, Ulewics 2021).

Various studies have been carried out for years on the recycling properties of thermoset composites. The descriptions related to the technologies regarding the potential recycling and/or reusing methods for end-of-life composites including, thermal, material, a chemical recycling are given in the literature (Cunliffe and Williams 2003, Oliveux et al.).

Nouigues et al. evaluated the thermo-mechanical behaviours of composites to understand their recycling properties. Various static and dynamic tests at different temperatures (ambient-150°C) were applied over glass transition temperatures (Tg). Higher resistance results were obtained in static flexion and traction from woven glass fibers reinforced unsaturated polyester composites than mixed chopped and woven glass fibers. Results revealed that in the case of the end-of-life wastes total degree of deformation (hydrolyzed composites) is higher than production wastes (virgin composites), recycling end-of-life wastes would be easier than production wastes (Nouigues et al. 2020).

Re-using potential of Glass Reinforced Polyester (GRP) pipe dust, which is a waste that occurs during the manufacturing process, in GRP pipe production has been investigated by Memioğlu et al. GRP pipe dust, was used as 2.5%, 5%, 7.5% and 10% of the total amount of silica sand that is used for pipe producing. It has been determined that the manufacturing of GRP pipe, which has better mechanical properties, fulfil the required values defined in standards and can be designed for different kind of projects can be done by using waste pipe dust. Also, it has been presented that the integration of waste dust in production is a useful approach in terms of waste management (Memioğlu and Dağlı 2019).

A study of using Grp pipe production wet cutting stage wastes in situ $CaCO_3$ which is used as filler in PVC pipe production proposed by Özüyağlı et al. Wet cutting stage wastes consist of silica, unsaturated polyester resin, and glass fiber. It has been presented that using GFRP waste powder in PVC production as a filler result in high flexure and tensile strength and hardness while thus lowering the density of composite (Özüyağlı et al. 2016).

Beycioğlu et al. evaluated using the GFRP pipe production wastes powders as a filler in asphalt mixes by a lab test. Positive results were obtained from applied tests from 4.5% binder content, 3.75% GRP-WP, and 1.25% limestone filler content samples. Utilizing GFRP production waste powders in hot mix asphalt production is a good solution for GFRP waste powder recycling (Beycioğlu et al. 2020).

In another study, Cunliffe et al., evaluated mass balance, pyrolysis gas, and condensable products properties through pyrolyzing GRP/styrene copolymer waste in a fixed-bed reactor. Re-using recovered glass fibers from pyrolyzing was also considered in this study. It is presented that it is easy to obtain glass fibers from the mixture. It was found that glass fibers can be used in test plaques and sample pieces as DMC in polyester composites (Cunliffe and Williams 2003).

Sabau et al. studied determining new composites that consist of recovered waste glass fibers. The polyester was used as a matrix and waste glass fibers were used as reinforcement and sand as filler in this new composite. It is mentioned that the satisfying mechanical properties have been gathered from new composite materials (Sabau et al. 2012).

Machinability of GFRP Khan et al. evaluated the composite material using alumina cutting tools. The performance of the SiC whisker reinforced alumina cutting tool is better than that of the Ti[C,N] mixed alumina cutting tool on machining GFRP composite (Khan and Kumar 2010).

Yıldız et al. applied various lab tests on composites to evaluate the utilizing properties of GRP wastes. Mechanical size reduction was applied to GRP wastes and the obtained three different grain sizes were used as filler in the production of new composites. The hand lay-up moulding technique was recommended as a production method since it allows adding wastes during the production and thus it is easy to apply gel-coat. Lower linear shrinkage and mechanically derived from the applied tests. It is also observed that using higher grain sizes rises glass transition temperature. It is recommended as an environmental solution that utilizes the reduced wastes particles in composites' structure (Yıldız et al. 2020).

In another study implemented by Ribeiro et al., utilizing GFRP pultrusion production end-of-life wastes in new composite production possibilities was investigated. GFRP grinded wastes are utilized in the polyester matrix as filler and reinforcement at various size distributions and loads. It is presented that using GFRP wastes as filler material rises the flexural and compressive behaviour of the composites (Ribiero et al. 2014).

2. TsGFRP Composite Waste Management

Polymers and composites are divided into two different groups as thermoset and thermoplastic. Thermoplastics soften and melt with the effect of heat, they can be reshaped. They are easily soluble in suitable solvents. These features allow the development of various solutions for the recovery of thermoplastic composites. Thermoset resins, on the other hand, cannot be melted or reshaped by heat due to the intense cross-linked network. At high temperatures, they decompose as a result of chain and bond breaks. Thus covalent cross-linked networks limited TsGFRP composites' recyclability.

The European Parliament and the Council Waste Management Hierarchy;

1 - Prevention should be preferred as the first application. This part consists of the precautions that can be taken before the product is manufactured. Just as re-designing product content. Thus maybe using environmental friendly, sustainable raw materials aiming to produce easily recyclable and re-usable products.

2 -Reusing the waste should be the second preference. Reusing the tolerable damaged GFRP pipes in irrigation and drainage lines can be given as an example.

3 - Recycling is the third preference of the waste management hierarchy. The most preferred method of recycling is grinding the wastes in different sizes and utilizing these particles in other material production. It is difficult to find effective usage ara for that kind of production and the energy demand of grinding should be considered.

4 - Since the incineration process has its own wastes needed to be managed on account of environmental concerns "incineration" is considered as the last preference.

5 - The disposal method is used when it is not possible to use other options and it should be mentioned that landfilling is not legal in some countries. Unfortunately, limited recycling structure of GFRP composites typically comes out with landfilling (Bernates et al. 2021, Post et al. 2020).

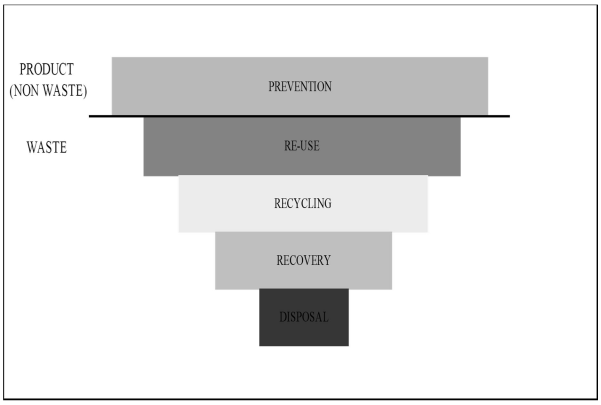


Figure 3. Waste management hierarchy (Bernates et al.)

3. TsGFRP Composite Waste Management

Mostly used TsGFRP composite waste recycling methods are chemical, thermal, and mechanical.

3.1. Chemical Methods

Chemical recycling can be defined as a dissolving matrix of composite waste materials in solvent or with heated water (<400°C) to recover valuable fillers and fibers or resin used as a matrix or monomers. This method is especially suitable for long fibers (Oliveux et al. 2012, Shuaib and Mativenga 2016).

3.2. Thermal Methods

Composite materials exposed with temperature treatment for leading recovery of intended reinforcement materials or energy sources.

3.2.1. Conventional Pyrolysis

Pyrolysing method depends on thermally degrading thermoset polymer with oven heating in an inert atmosphere. Recovered oil and gas from the pyrolyze process can be used as an energy source. Additionally, fiber sizing should be needed for use in other composites (Oliveux et al. 2012, Shuaib and Mativenga 2016).

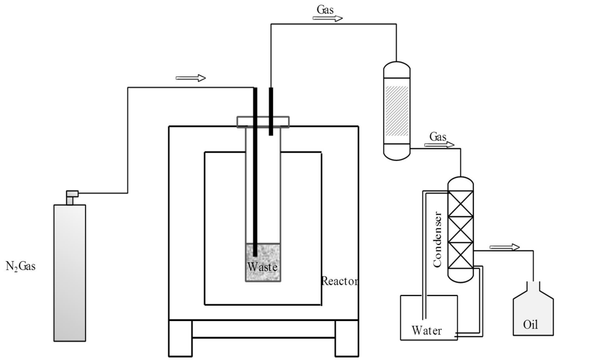


Figure 4. A diagram of the bench-scale pyrolysis reactor (Shuaib and Mativenga 2016).

3.2.2. Microwave Pyrolysis:

Microwave pyrolyzing method depends on degrading thermoset polymer with microwave heating in an inert atmosphere. Fastly heating process and low energy demand considered as a benefit but being is applicable in laboratory scale is a handicap of this method. Obtaining cost-effective products from the pyrolysis process (Shuaib and Mativenga 2016, Akesson et al. 2013).

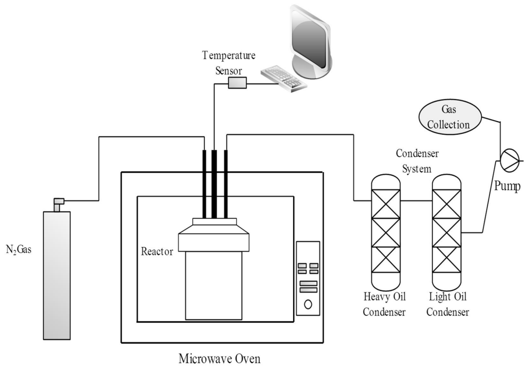


Figure 5. Schematic outline of the experimental set-up for micro-wave pyrolysis (Shuaib and Mativenga 2016).

3.2.3. Fluidized Bed:

The process depends on heating (450-650 °C) composites on a silica bed with an airstream for dissolving the matrix of composite materials for gaining reinforcement or fillers (Shuaib and Mativenga 2016).

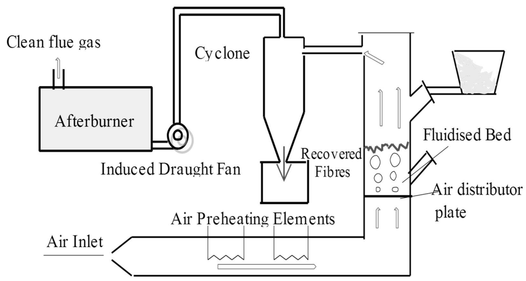


Figure 6. Schematic diagram of a fluidized bed thermal process

3.2.4. Incineration

TsGFRP composite wastes are valuable fuel sources such as coal because of their heating value. It is possible to reduce the waste volume by about 90–95% after incineration. Nonetheless, this process has residues such as fly ash and bottom ash which require treatment or disposal. This process occurs another wastes problem and this made it a noneffective method for recycling TsGFRP composite wastes (Kutluata 2009).

3.3. Mechanical Methods

The Mechanical recycling method depends on reducing the size of composite wastes to utilize recycles in another composite production as partial reinforcement or fillers.

Material sizes that are less than 100 mm in size are considered powder-rich and sizes around 5-10 mm in length are considered fiber-rich. It is applicable on an industrial scale. Limited secondary market values are a disadvantage of this method (Özüyağlı et al 2016, Shuaib and Mativenga 2016).

4. Conclusion and Recommendations

Composite materials are high-performance products produced with the latest technologies. They consist of many different fibers and fillers used in matrices with different properties for gaining the desired properties. That matter complicates the recycling properties of TsGFRP composite wastes. In addition to providing superior performance to the materials, the recycling properties of end-of-life TsGFRP composite wastes are very limited due to their intense covalent crosslinked bonds. Recycling methods of TsGFRP composite waste disposal methods have advantages and disadvantages, but the most important issue of these methods is being low value-added and typically requiring a high energy input and requiring additional costs to the manufacturers.

Since recycling and recovery infrastructures for TsGFRP composite end-of-life wastes have not been established yet, it is widely used as a landfilling and incineration disposal method. These methods, which are used because they are easily applicable and low-cost solutions, are not considered sustainable practices due to economic, social, and environmental concerns.

In the studies carried out to find solutions in this regard, it is aimed to use TsGFRP composite wastes as reinforcement and/or filling material in other composite structures by reducing the size of the wastes after mechanical processes, such as crushing, shredding, and grinding. In the literature, there are many studies on the use of TSGFRP composite wastes, which are reduced in size, as reinforcement or filling material. Among the recycling applications applied to TsGFRP composite waste, mechanical processes are accepted as the most effective and efficient technique with commercial potential. It also provides an advantage in terms of not having a direct environmental impact. Despite all its advantages and studies in the literature, its industrial potential is limited due to the limited availability of easy-to-apply and cost-effective end-uses and the lack of a secondary market for recycled materials.

Despite all the advantages of TsGFRP composite materials, the recycling of end-of-life TsGFRP composite wastes become challenging for manufacturers. For this reason, designing the composites to be produced as the raw material of another product at the end of their service life, and prioritizing recycling technologies with advanced separation and cleaning methods will be the best solution to the problem.

5. References

Akesson, D., Foltynowicz, Z., Christeen, J. and Skrifvars, M., 2013. Products obtained from decomposition of glass fiber-reinforced composites using microwave pyrolysis. Polymery Polimery/Polymers, 2013, 58(7-8): p. 582-586.

Bernates, R., Dagreu S., A. Despax-Ferreres, Barasinski, A., 2021. Recycling of fiber reinforced composites with a focus on thermoplastic composites. *Cleaner Engineering and Technology* (Elsevier). Vol. 5, 100272.

Beycioğlu, A., Kaya, O., Yıldırım, Z. B., B, Bağrıaçık., Dobiszewska, M., Morova, N. and Çetin, S., 2020. Use of grp pipe waste powder as a filler replacement in hot-mix asphalt. *Materials, Oct* 2020, Vol. 13 (20), p. 4630 15p.

Cunliffe, A. M. and Williams, P., 2003. Characterisation of products from the recycling of glass fibre reinforced polyester waste by pyrolysis. *Fuel (*Elsevier). Dec 2003

Vol. 82 (18) p.2223-2230.

Demirel, Ü., 2008. Desinging of hydrostatic pressure testing machine in high flow sytem. MSc Thesis. Yıldız Technical University, Institute of Science, Istanbul, 115

Ianasi, C., 2020. Aspects regarding reinforcement with composite materials. Annals of 'Constantin Brancusi' University of Targu-Jiu. Engineering Series. Issue 2, p157-160. 4p. Romania.

Kaya, A. İ., 2016. Composite Materials and their properties. Putech-Composites, Vol:3, p.38-45.

Khan, M. A. and Kumar, A.S., 2010. Machinability of glass fibre reinforced plastic (gfrp) composite using alumina-based ceramic cutting tools. Journal of Manufacturing Processes (Elsevier), Vol. 13 (2011) p. 67–73.

Kutluata, G., 2009. Studies on The Recycling of Glass Fiber Reinforced Polyester Resin Composite, MSc Thesis, Ege University Graduate School of Applied and Natural Sciences, Izmir, 51.

Memioğlu, F. and Dağlı E., 2019. Utilization of glass fiber reinforced polyester (GFRP) waste in concrete production. 10th International Concrete Congress. Bursa-Turkey.

Ming, Y., Chen, P., Li, L., Gan, G.and Pan, G., 2021. A comprehensive review on the utilization of recycled waste fibers in cement-based composites. Materials, Jul 2021, Vol. 14 (13), p.3643 28p.

Nouigues, A., E, Le Gal La Salle., and Bailleul, J-L., 2020. Thermo-mechanical characterization of unsaturated polyester/glass fiber composites for recycling. International Journal of Material Forming. (2021) Vol. 14, p. 153-174.

Oliveux, G., Bailleul, J-L. and E, Le Gal La Salle., 2012. Chemical recycling of glass fibre reinforced composites using subcritical water. Composite Part A: Applied Science and Manufacturing (Elsevier) Vol. 43 (11) p. 1809-1818.

Özüyağlı, A., Mehmetalioğlu C., Özsoy and M., Akıncı, A., 2016. Investigation of mechanical properties of gfrp pipe production waste filled pvc matrix composites. Journal of the Faculty of Engineering and Architecture of Gazi University. Vol. 31, No 2, p. 465-472

Post, W., A, Susa., Blaauw, R., Molenveld, K. and Knoop, R.J.I., 2020. *A Review on the Potential and Limitations of Recyclable Thermosets for Structural Applications*. Polymer reviews. Vol. 60 (2), p. 359–388.

Ribeiro, M.C.S., Fiúza, A., Meira-Castro, A.C., Silva, F.G., Meixedo, J.P. and Dinis, M.L., 2014. A case study undertaken recycling & reuse of glass fiber reinforced thermoset polymer wastes of composite materials industry. Materials Science Engineering.

Sabau, E., Balc, N., Bere, P., Bere and Nemeş, O., 2012. New Materials From Waste Glass Fibre. Studia Universitatis Babes-Bolyai, Chemia. *Dec 2012, Vol. 57 (4), p. 201-208.*

Shuaib, N.A. and Mativenga, P.T., 2016. Energy demand in mechanical recycling of glass fibre reinforced thermoset plastic composites. Journal of Cleaner Production Vol. 120, p. 198-206.

Sönmez, M., 2009. The importance and future of poymeric composites in industrial product design: A study on four companies from Turkey. MSc Thesis, Istanbul Technical University, Institute of Science, Istanbul, 183.

Ulewics, M., 2021. Recycled materials for concrete and other composites. Materials, May 2021, 14 (9), p.2279 3p.

Yıldız, S., Karaağaç, B. and Güzeliş, S.G., 2020 Utilization of glass fiber reinforced polymer wastes. Polymer Composites. 2021; Vol. 42: p.412–423.

Internet resources

1-https://www.turkchem.net/polyester-recinesi-kullanim-alanlari.html

2.https://kalkinmaguncesi.izka.org.tr/index.php/2021/03/24/kompozit-malzemeler-sektoru-ve-turkiyenin-durumu

AFYON KOCATEPE ÜNİVERSİTESİ ULUSLARARASI MÜHENDİSLİK TEKNOLOJİLERİ ve UYGULAMALI BİLİMLER DERGİSİ

Afyon Kocatepe Üniversitesi
Ahmet Necdet Sezer Kampüsü
Teknoloji Fakültesi
AFYONKARAHİSAR
Tel: +90 272 228 14 46
Belgegeçer: +90 272 228 14 49
E-posta: ijetas@aku.edu.tr

www.ijetas.aku.edu.tr