
**Düzce University**
**Journal of Science & Technology**

*Research Article*

# Effect of Natural Aging on Mechanical Properties of Copper Clad Steel Brake Pipes

Ozan KOYUNCU[a], Burak ÇELİK[a], İrem Yağmur SİMİTÇİ[a], Yasin AKGÜL[b,c], Alper İNCESU[b,d,*]

[a] *Bant Boru San. ve Tic. A.Ş., Ar-Ge Departmanı, 41480 Gebze/Kocaeli, TURKEY*
[b] *K-O Faktör Techology and Engineering, 78050, Karabük, TURKEY*
[c] *Iron and Steel Institute, Karabuk University, TURKEY*
[d] *TOBB Tech. Sciences Vocational School, Karabuk University, 78050, Karabuk, Turkey*

* *Corresponding author's e-mail address: alperincesu@karabuk.edu.tr*
DOI: 10.29130/dubited.1604223

## ABSTRACT

Copper-clad steel tubes are the basic components of the hydraulic systems of many products, especially automobile brake systems. The mechanical properties of copper-clad steel tubes produced for use in the automotive industry are determined by acceptance criteria. After production, they are expected to maintain these properties during the stock and transfer process. However, metallic materials may undergo natural aging when kept at room temperature for a long time. In this study, the changes in the mechanical properties of copper-clad steel tubes of different diameters (ø4.75, ø6, ø8 mm) were investigated by keeping them at room temperature for 1 year. The mechanical properties were characterized by tensile and blasting tests, and the changes in mechanical properties were investigated by examining the microstructure using an optical microscope. Results showed that there are no significant microstructural changes while there was a slight decrease in the tensile properties of brake pipes.

***Keywords:*** *Copper-clad steel tube, mechanical properties, microstructure, natural aging.*

# Doğal Yaşlanmanın Bakır Kaplı Çelik Fren Borularının Mekanik Özellikleri Üzerindeki Etkisi

## ÖZ

Bakır kaplı çelik borular, otomobil fren sistemleri başta olmak üzere birçok ürünün hidrolik sistemlerinin temel bileşenleridir. Otomotiv sektöründe kullanılmak üzere üretilen bakır kaplı çelik boruların mekanik özellikleri kabul kriterleri ile belirlenir. Üretim sonrası stok ve transfer sürecinde de bu özelliklerini korumaları beklenir. Ancak metalik malzemeler oda sıcaklığında uzun süre bekletildiklerinde doğal yaşlanmaya uğrayabilirler. Bu çalışmada, farklı çaplardaki (ø4.75, ø6, ø8 mm) bakır kaplı çelik borular 1 yıl boyunca oda sıcaklığında bekletilerek mekanik özelliklerindeki değişimler incelenmiştir. Mekanik özellikler çekme ve patlatma testleri ile karakterize edilmiş ve mekanik özelliklerdeki değişiklikler optik mikroskop kullanılarak mikroyapı incelenerek araştırılmıştır. Sonuçlar, fren borularının çekme özelliklerinde hafif bir azalma olurken önemli bir mikroyapısal değişiklik olmadığını göstermiştir.

***Anahtar Kelimeler:*** *Bakır kaplı çelik boru, mekanik özellikler, mikro yapı, doğal yaşlanma*


Received: 20/12/2024, Revised: 14/02/2025, Accepted: 03/03/2025

# I. INTRODUCTION

As a layered metallic composite material, copper-clad steel sheets are among the most successful types of laminated metal matrix composites, widely used in electrical industries, automobile manufacturing, armor, and fusion reactor applications. Their unique combination of fracture toughness, strength, electrical conductivity, corrosion resistance, and radiation shielding properties makes them ideal for demanding applications [1]. Various methods, including electroplating, chemical plating, diffusion bonding, magnetron sputtering, arc welding, blast welding, and roll bonding, can be used to apply copper coatings onto steel sheets [2].

In automobile hydraulic brake systems, brake pipes are generally produced using copper-coated steel sheets due to their excellent mechanical properties and corrosion resistance [3]. Typically, DC03 quality steel sheets (0.35 mm thickness) are electroplated with a 3-5 μm copper layer, followed by bending (720°), soldering, and heat treatment at 1050 °C to ensure strong bonding [4]. These tubes, also known as Bundy Tubes (Figure 1), are crucial in hydraulic brake systems and compressors, significantly impacting the performance and safety of braking mechanisms [2].

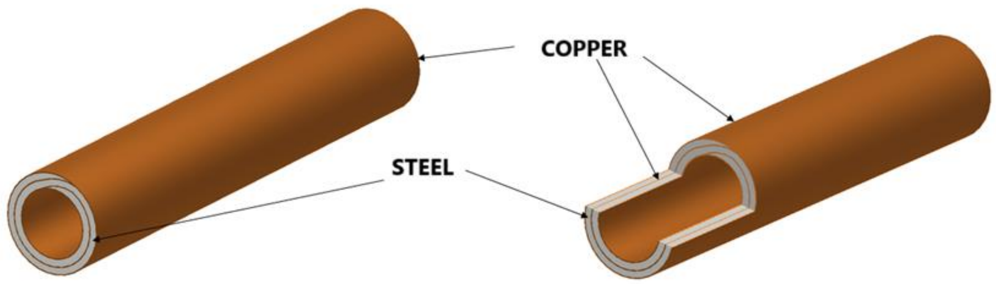


***Figure 1.*** *Schematic view of Copper Clad Double Walled Steel Tube [2].*

Brake pipes often remain in stock or undergo prolonged transportation before being assembled into vehicles. During these extended storage periods, metallic materials may experience natural aging, which can lead to subtle mechanical property changes over time. Unlike artificial aging where accelerated thermal treatments mimic long-term effects natural aging occurs at room temperature, making its effects more difficult to predict and control [5]. This is because natural aging can be mimicked by accelerating natural aging with artificial aging applied by isothermal treatment at 100 to 350 °C [6]. Homma et al. [7] reported that aging at 250 °C for 1 hour for low-strength steel is equivalent to 2 years of natural aging. While numerous studies have examined artificial aging [8], [9], [10], research focusing on the effects of natural aging on copper-clad steel brake pipes is limited.

The primary aim of this study is to investigate the effects of natural aging on the mechanical properties of copper-clad steel brake tubes over a period of one year. Instead of simulating aging through artificial means, the materials were stored under normal storage conditions to reflect real-world scenarios. Tensile and blasting tests were performed every three months, and microstructural analysis was conducted using optical microscopy to assess changes in mechanical properties.

The novelty of this research lies bridging the knowledge gap by examining the effects of natural aging on copper-clad steel brake pipes—a topic that has received little attention in the literature. Also, industrial relevance by evaluating the long-term performance of brake pipes in real-world conditions was explained by offering insights for manufacturers to improve quality control and predict potential mechanical property variations during storage and transportation. This study contributes to enhancing the reliability, durability, and safety of brake systems in the automotive industry by understanding how natural aging impacts mechanical properties.

# II. MATERIALS AND METHODS

The copper-coated steel pipes (brake pipes) with a diameter of 4.75, 6, and 8 mm used in the study were obtained from Bant Boru (Turkey). Bant Boru produces brake pipes by copper plating the sheet material whose chemical composition is given in Table 1 and mechanical properties are given in Table 2 and then applying the "roll forming" method to the copper plated sheet. The results in Table 1 and Table 2 were obtained experimentally from the sheets used in pipe production in our previous study [2]. In brake tube production, double folding is performed, and copper is welded between the steel surfaces by applying a temperature above the melting temperature of copper.

***Table 1.*** *Chemical composition of DC03 grade sheet material used in brake pipe production (wt.%)*

| C | Mn | Si | P | S | N | Al | Cr | Ni | Cu | B | Mo | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0,04 | 0,23 | 0,007 | 0,013 | 0,014 | 0,027 | 0,033 | 0,03 | 0,021 | 0,043 | 0,001 | 0,002 | Balance |

***Table 2.*** *Mechanical properties of DC03 quality sheet material used in brake pipe production*

| Tensile Strength (MPa) | Yield Strength (MPa) | Elongation (%) | Hardness (HV1) |
|---|---|---|---|
| 346,3±2,1 | 192±1 | 37,4±0,2 | 102±1 |

Pipes with diameters of 4,75, 6 and 8 mm (Figure 2) were kept at room temperature for 1 year and a natural aging process was carried out. The microstructural differences were examined with a Nikon Eclipse MA200 inverted metallurgical optical microscope. Microstructural changes in the samples were examined with Nikon Eclipse MA200 inverted metallurgical optical microscope. Before microstructure examinations, sanding with SiC papers (200, 400, 600, 800, 1200, 2000, 2500 grit), polishing (1 and 3 μm diamond suspensions) and etching (5% Nital solution) metallographic processes were applied [11]. Tensile tests were performed on a Zwick/Roell Z600 Universal Testing Machine at a test speed of 2 mm/min following TS EN ISO 6892-1 (ISO 2016) tensile test standard for metallic materials. The test length at which the elongation was measured was taken as 20 mm by the cross-sectional area of the pipes.


***Figure 2.*** *Natural aged pipe sample figures before and after tensile test.*

The blasting test was performed following ASTM A 254, SAE J 1677 standards (Figure 3). For the blasting test, DOT 3 hydraulic brake fluid was filled into the pump of Enerpac Company and one end of the part to be tested was closed with a blind plug. The applied pressure and the test results at the moment of detonation are displayed on a 2500-bar analog manometer. The obtained results were subjected to statistical analysis using one-way analysis of variance (ANOVA) and presented as mean ± standard deviation. The significance of differences ($p < 0.05$) among the data sets was determined using the IBM-SPSS 22.0 statistical package (SPSS Inc., Chicago, IL, USA). Group means were further compared utilizing the Duncan multiple comparison test. All analyses were conducted in triplicate under consistent experimental conditions.

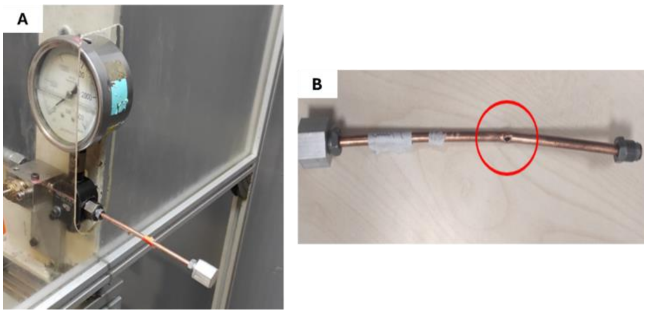


***Figure 3.*** *a) Connecting the part to the system, b) Sample image of the fragment after blasting test.*

# III. RESULTS AND DISCUSSION

The microstructures of naturally aged pipes with 4.75 mm, 6 mm, and 8 mm diameters at the end of 0, 3, 6, 9, and 12 months are presented in Figure 4, Figure 5, and Figure 6, respectively. As shown in Table 1, the brake pipes are made of steel sheets with a C content of about 0.04 wt. %. Therefore, the amount of cementite and pearlite formation due to cementite is very low. The microstructure of the specimens generally consists of ferrite grains. It is generally expected that grain growth occurs as a result of natural aging due to atomic diffusion over time [12]. However, optical microscopy images revealed no significant changes in grain size or phase structure. One possible explanation for this is the insufficient duration of the experiment. For instance, Yakovleva et al. [5] reported that microstructural changes in steel subjected to natural aging over 12 years led to measurable differences in phase distribution and mechanical properties. In a study on high-cycle fatigue behavior of steels, Li et al. [13] observed that long-term natural aging (~20,000 hours) promoted grain boundary changes and crack initiation sites. However, this effect was not observed in the current study, possibly due to the shorter aging period. This suggests that significant grain coarsening to occur, much longer durations of natural aging may be necessary. Furthermore, low-carbon steel aging studies have shown that aging at room temperature can lead to slight carbon redistribution and dislocation rearrangements, which may not be clearly visible in optical microscope images but can still affect mechanical properties [14].

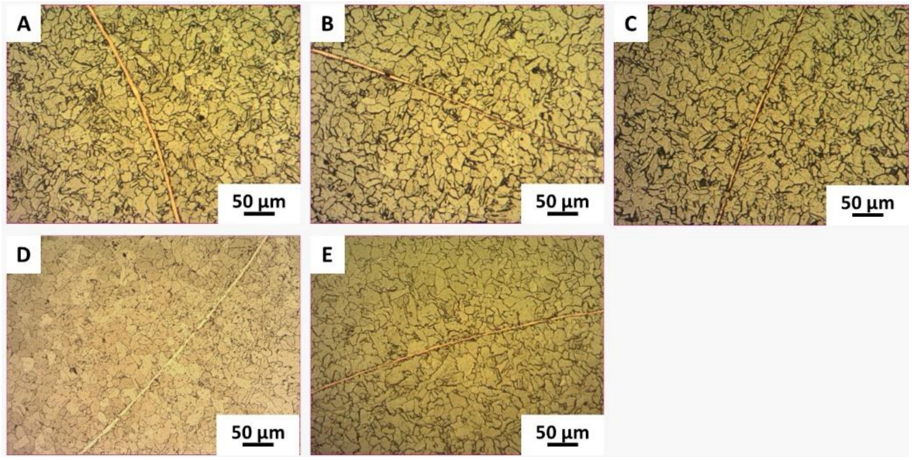


***Figure 4.*** *Microstructures of 4,75 mm diameter natural aged pipes at the end of a) 0. Month, b) 3. Month, c) 6. Month, d) 9. Month, e) 12. Month*

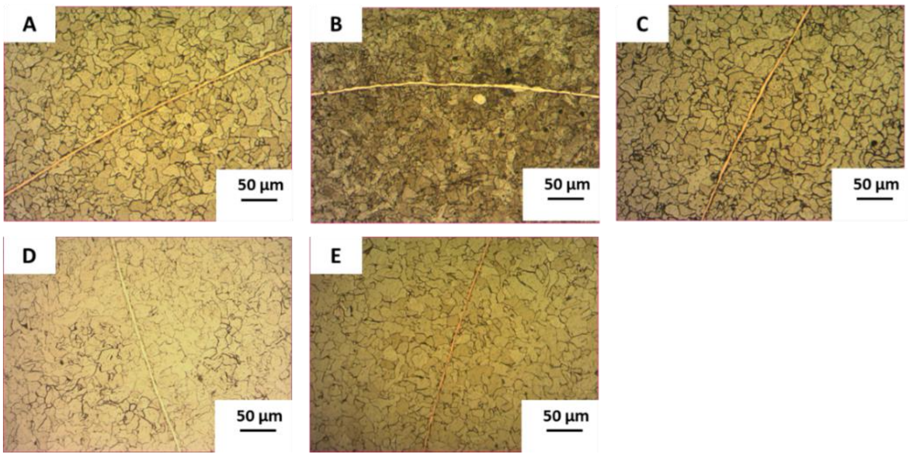


***Figure 5.*** *Microstructures of 6 mm diameter natural aged pipes at the end of a) 0. Month, b) 3. Month, c) 6. Month, d) 9. Month, e) 12. Month*

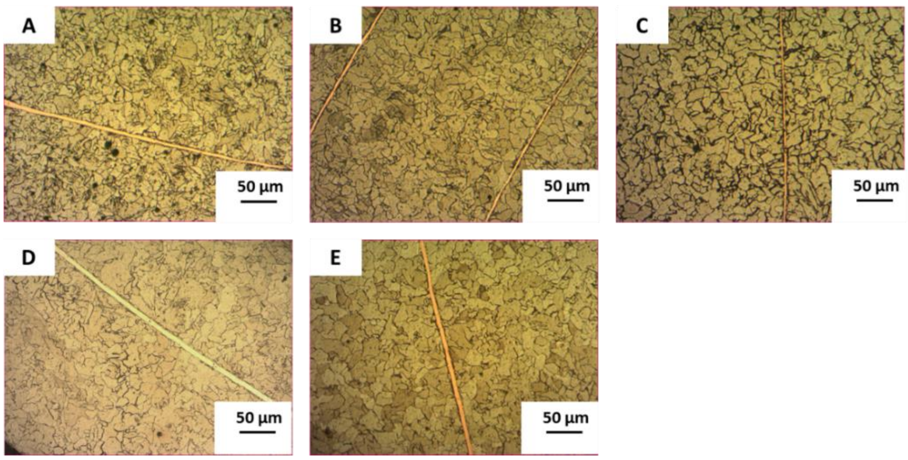


***Figure 6.*** *Microstructures of 8 mm diameter natural aged pipes at the end of a) 0. Month, b) 3. Month, c) 6. Month, d) 9. Month, e) 12. Month*

The tensile strength of the samples over time is presented in Figure 7. A decrease in tensile strength was observed for all pipe diameters because of 12 months of natural aging. The decrease in tensile strength was 3.7%, 1.7%, and 2.8%, with an average reduction of 2.7%. One possible explanation for this decrease is the rearrangement of dislocations, which leads to internal stress relaxation and slight softening [15]. This is consistent with the findings of De et al. [16], who reported that dislocation relaxation and carbon atom segregation at dislocations can contribute to a reduction in strength. Additionally, Zamani et al. [17] demonstrated that in low-carbon dual-phase steels, natural aging at room temperature could cause quench aging effects, leading to changes in mechanical properties over time. Another contributing factor may be cementite precipitation at grain boundaries, which can cause localized weakening in the ferrite matrix [18]. However, the effect in this study was not as pronounced, suggesting that either the aging time was too short, or the steel composition limited precipitation effects.

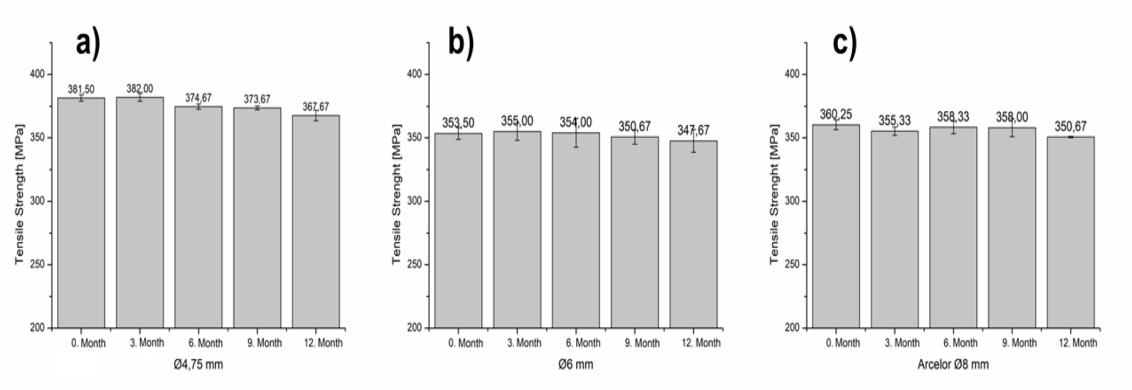


***Figure 7.*** *Tensile Strengths of Samples*.

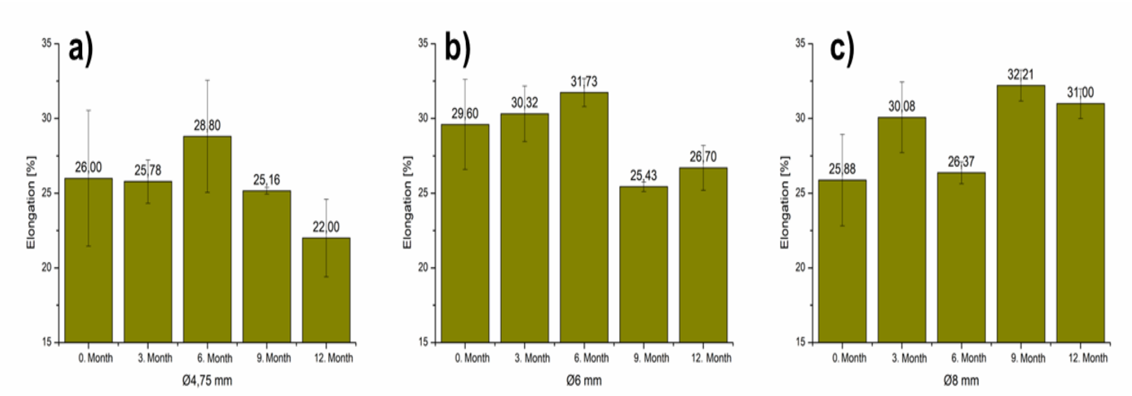


***Figure 8.*** *Elongations of Samples*

Figure 8 illustrates the elongation behavior of the samples. Notably, the standard deviations for elongation values are relatively high, suggesting variability in deformation behavior. While the overall trend indicates a decrease in elongation for 4.75 mm and 6 mm pipes, the 8 mm diameter samples did not follow this trend. One possible reason for the inconsistent behavior of the 8 mm samples could be grain boundary effects and differences in internal stress distributions. As suggested by González-Arévalo et al. [12], aging processes can influence burst pressure and failure probability in steel pipelines, particularly when combined with residual stresses from manufacturing processes. Additionally, cementite precipitation at grain boundaries can reduce ductility by increasing local embrittlement [18], [19]. While this study did not directly measure precipitation formation, future investigations using TEM could provide further insight into the precipitation kinetics and their effects on mechanical properties.

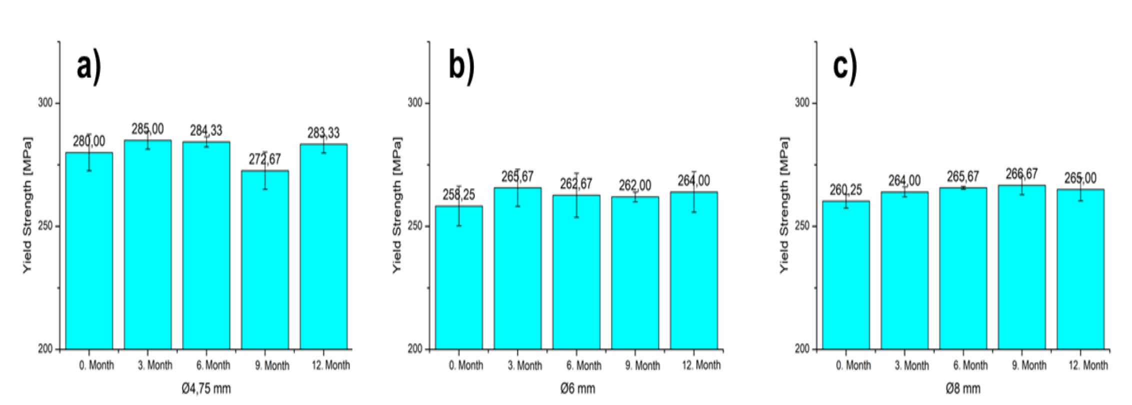


***Figure 9.*** *Yield Strength of Samples*

The yield strength of the brake pipes is presented in Figure 9. Unlike tensile strength, yield strength increased by approximately 1.7% on average at the end of the natural aging period. This increase may be attributed to the formation of dislocation networks and carbon clustering, which can act as obstacles to dislocation movement. Kawahara et al. [14] showed that carbon clustering and fine carbide precipitation in low-carbon steel significantly enhance yield strength through increased resistance to dislocation glide. Furthermore, Zamani et al. [17] demonstrated that low-temperature aging can induce a strengthening effect via the formation of fine precipitates in ferrite grains. As mentioned above, cementites can form precipitates at grain boundaries. As a result, elongation at break may decrease and yield strength may increase with the resulting brittle structure [20]. These findings align with our results, suggesting that natural aging may cause localized strengthening mechanisms despite the overall softening observed in tensile strength measurements.

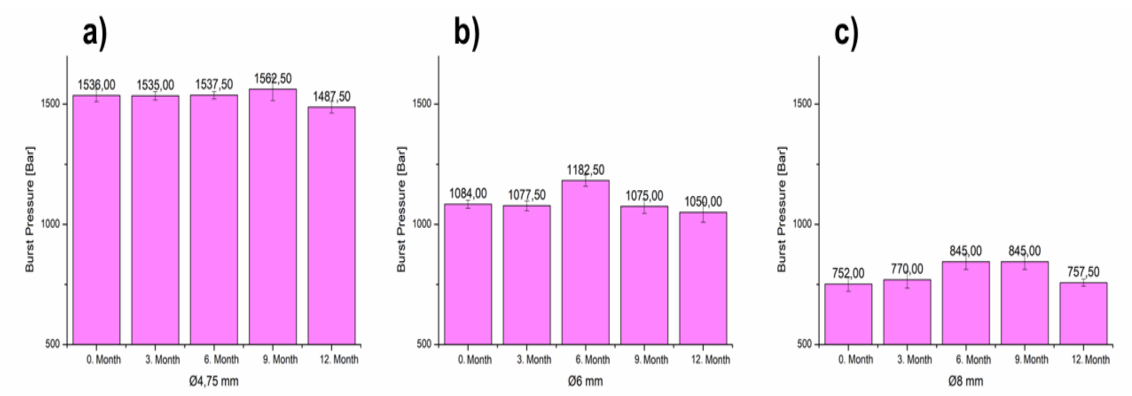


***Figure 10.*** *Bursting Pressure of Samples*

The bursting pressure results are shown in Figure 10. In general, bursting pressures decreased with aging, except for the ø8 mm sample. Since bursting pressure is closely linked to material toughness, the observed reduction suggests that aging negatively impacts the toughness of the brake pipes [21]. This is supported by findings from González-Arévalo et al. [12], who studied the influence of aging on burst pressure predictions in pipeline steels. Their research showed that aging effects, combined with environmental factors such as corrosion, can lead to significant reductions in burst pressure over time.

In the context of brake pipes, this indicates that long-term storage could impact safety margins, particularly in extreme service conditions. Moreover, fatigue behavior studies by Li et al. [13] demonstrated that natural aging can alter crack initiation mechanisms, potentially affecting burst pressure performance. Future research should explore the combined effects of fatigue and natural aging, as well as the role of environmental conditions in aging-related toughness reductions.

# IV. CONCLUSION

This study investigated the effects of natural aging on the mechanical properties of copper-clad steel tubes with different diameters (4.75, 6, 8 mm) over a one-year storage period at room temperature. The findings indicate that while no significant microstructural changes were observed, natural aging resulted in a slight decrease in tensile strength (≈2.7%) and an increase in yield strength (≈1.7%). Additionally, blasting pressure and elongation at break values showed a decreasing trend, except for the sample with a diameter of 8 mm. The results of this study are highly relevant to industries where long-term storage and transportation of brake tubes are common, particularly in the automotive sector. Since copper-clad steel brake pipes are critical components in hydraulic braking systems, even small changes in mechanical properties can influence performance, durability, and safety. Manufacturers and suppliers should consider natural aging effects in their quality control processes, especially when evaluating long-term stockpiling or transportation conditions. Future studies should focus on longer-term aging effects beyond one-year, detailed microstructural analysis using TEM, and the combined impact of corrosion and natural aging on mechanical properties. Additionally, comparative studies with artificial aging processes could help bridge the gap between accelerated laboratory testing and real-world performance.

ACKNOWLEDGEMENTS: The authors would like to thank Bant Boru A.Ş. and Karabük University Iron and Steel Institute for their support of this study.

# V. REFERENCES

[1] D. Nedelcu and I. Carcea, “Technology for obtaining samples of layered composite materials with metallic matrix,” *Met. Mater. Int.*, vol. 19, no. 1, pp. 105–112, 2013.

[2] O. Koyuncu, B. Çelik, Y. Akgül, and A. İncesu, “Isıl İşlemin Bakır Kaplı Çelik Boruların Mekanik Özelliklerine Etkisinin Araştırılması,” *J. Mater. Mechatron. A*, vol. 4, no. 1, pp. 177–192, 2023.

[3] D. K. Miner, “Automotive hydraulic brake tube: the case for 90-10 copper-nickel tubing,” in SAE International Congress and Exposition, Detroit, USA, 1993.

[4] O. Koyuncu, B. Çelik, Y. Akgül, and A. İncesu, “Farklı Hız ve Sabit Oranda Uygulanan Redüksiyonun Fren Boruların Mekanik Özelliklerine Etkisinin Araştırılması,” *Çelik Araşt. Ve Geliştirme Derg.*, vol. 4, no. 1, pp. 17–23, 2023.

[5] E. A. Yakovleva, A. V. Larionov, G. D. Motovilina, and E. I. Khlusova, “Effect of Natural and Artificial Aging on Steel Mechanical Properties and Fracture Toughness,” *Inorg. Mater. Appl. Res.*, vol. 13, no. 6, pp. 1490–1498, 2022.

[6] G. Krauss, *Steels: Heat Treatment and Processing Principles*, 1st ed., Materials Park, OH, USA: ASM International, 1990, pp. 44–50.

[7] K. Homma, C. Miki, and H. Yang, "Fracture toughness of cold worked and simulated heat affected structural steel," *Eng. Fract. Mech.*, vol. 59, no. 1, pp. 17–28, 1998.

[8] G. Xu, Y. Yang, and X. Zhang, "Study of aging behavior of CSP hot bands for cold sheets," *Mater. Charact.*, vol. 59, no. 9, pp. 1355–1358, 2008.

[9] T. Trzepieciński and S. M. Najm, "Current trends in metallic materials for body panels and structural members used in the automotive industry," *Materials*, vol. 17, no. 3, p. 590, 2024.

[10] P. Bałon *et al.*, "A method of manufacturing car mufflers by wrapping sheets, using innovative forming device with the use of servo drive," *Procedia Manuf.*, vol. 50, pp. 17–21, 2020.

[11] O. Koyuncu, B. Çelik, Y. Akgül, and A. İncesu, "Aynı Sıcaklıkta Uygulanan Isıl İşlem ve Farklı Oranda Uygulanan Redüksiyon İşleminin Fren Borularına Mekanik Özelliklerine Etkisinin Araştırılması," *Çelik Araşt. Ve Geliştirme Derg.*, vol. 5, no. 1, pp. 1–8, 2024.

[12] N. E. González-Arévalo *et al.*, "Influence of aging steel on pipeline burst pressure prediction and its impact on failure probability estimation," *Eng. Fail. Anal.*, vol. 120, p. 104950, 2021.

[13] G. Li, L. Ke, W. Peng, X. Ren, and C. Sun, "Effects of natural aging and variable loading on very high cycle fatigue behavior of a bearing steel GCr15," *Theor. Appl. Fract. Mech.*, vol. 119, p. 103360, 2022.

[14] Y. Kawahara *et al.*, "Characterization of age hardening mechanism of low-temperature aged low-carbon steel by transmission electron microscopy," *Mater. Charact.*, vol. 183, p. 111579, 2022.

[15] V. L. Indenbom, "Dislocations and internal stresses," in *Modern Problems in Condensed Matter Sciences*, Amsterdam, Netherlands: Elsevier, 1992, ch. 1, pp. 1–174.

[16] A. K. De, K. De Blauwe, S. Vandeputte, and B. C. De Cooman, "Effect of dislocation density on the low temperature aging behavior of an ultra low carbon bake hardening steel," *J. Alloys Compd.*, vol. 310, no. 1–2, pp. 405–410, 2000.

[17] M. Zamani, H. Mirzadeh, and M. Maleki, "Enhancement of mechanical properties of low carbon dual phase steel via natural aging," *Mater. Sci. Eng. A*, vol. 734, pp. 178–183, 2018.

[18] G. Li, J. Liu, J. Sun, and C. Sun, "Effects of Natural Aging and Discontinuous Cyclic Loading on High Cycle Fatigue Behavior of Steels," *Metals*, vol. 13, no. 3, p. 511, 2023.

[19] T. D. Barlow, “Aging effects on the fatigue performance of deep rolled bar steels,” M.S. thesis, Faculty and Board of Trustees, Colorado School of Mines, Colorado, USA, 2013.

[20] F.-C. An, J.-J. Wang, S.-X. Zhao, and C.-M. Liu, “Tailoring cementite precipitation and mechanical properties of quenched and tempered steel by nickel partitioning between cementite and ferrite,” *Mater. Sci. Eng. A*, vol. 802, p. 140686, 2021.

[21] K. Yoshioka, Y. Zhang, G. Lu, A. Bunger, J. Adachi, and B. Bourdin, “Improving the Accuracy of Fracture Toughness Measurement in Burst Experiments,” *Rock Mech. Rock Eng.*, vol. 56, no. 1, pp. 427–436, 2023.