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Recommendation for the Utilization of Used ACSR Conductors Based on the Life Prediction Analysis of New and Used ACSR Conductors Reffering to Tensile Strength and Accelerated Thermal Aging Using the Arrhenius Method

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ABSTRACT

Aluminium Conductor Steel Reinforced (ACSR) is essential for high-voltage power transmission due to its electrical conductivity and mechanical strength. However, thermal aging over time can degrade its mechanical properties, affecting system reliability. This study investigates the impact of high-temperature treatment on ACSR's ultimate tensile strength and models its service life using the Arrhenius method. Testing was conducted at PT PLN's Low Voltage Laboratory with accelerated thermal aging at 90°C to 130°C. Results show that higher temperatures significantly reduce service life. At 130°C, new conductors' life dropped by 99.72%, while used ones decreased by 98.56%. These findings support asset management strategies for transmission systems.

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INTRODUCTION

ACSR conductors are widely used in high-voltage transmission networks due to their combination of aluminum's electrical conductivity and steel's mechanical strength. However, over time, the aluminum degrades, leading to a loss of tensile strength, elongation, and conductivity, with a typical degradation of 10–20%. The degradation is accelerated by environmental factors like friction, vibration, corrosion, and chemical exposure. The conductor lifespan is estimated at 25–30 years, with the degradation rate averaging 0.4–0.5% per year. Although new conductors are more resilient, used ACSR conductors show faster degradation, especially when exposed to high temperatures, with tensile strength reducing by up to 25% after 300 hours at 130°C.

The MRWI program aims to optimize material use by recycling or reusing materials, but not all old conductors are suitable for reuse. Research on the safe reuse of used ACSR conductors is limited, and more data is needed to assess their performance under high temperatures. At PLN UP3B Kalimantan, used conductors are stored in unsuitable conditions due to full warehouse capacity, which poses a challenge to their safe reuse. Regular technical evaluations and inspections are necessary to ensure the reliability and safety of reused conductors in power transmission systems.

Figure 1. Storage Conditions of Used Conductors in Warehouses

The image shows used conductors stored in an open warehouse, exposed to weather, humidity, and surrounding vegetation, which has led to signs of corrosion and oxidation on their surface, indicating material degradation. These poor storage conditions can accelerate the loss of mechanical properties, such as tensile strength, and electrical properties, impacting the reliability of the transmission line. As part of PLN’s MRWI program, which aims to optimize material reuse, a thorough evaluation of these conductors is necessary before they can be safely reused. This study uses accelerated thermal aging and the Arrhenius approach to analyze material degradation, providing valuable insights for decision-making regarding the disposal or reuse of stored conductors.

LITERATURE REVIEW

Table 1. Literature Review

Yes	Researcher Name	Research Title	Novelties	Year
1	Squirrel, Squirrel[12]	Study of the effect of high temperature on changes in the material structure of ASTM A36	Focus on ASTM A36 steel, not ACSR; see the effect of heating on toughness & tensile strength	2017
2	Dwight Dunn [13]	Effect of *post-heating* temperature variation on S45C steel welding	Focus on S45C steel weld results; Finding an increase in tensile strength and toughness at high temperatures as well as a reduction in residual stress.	2016
3	Silaban, Doly Prima[14]	Changes in the structure of the activated carbon of the coconut shell due to warming	Different materials (activated carbon), researching the adsorption capacity of heavy metals and morphological changes	2018
4	Meyzan Andreansyah, Ratna Dewi Anjani, Viktor Naubnome[15]	The effect of high temperature on the microstructure changes of steel and stainless steel	Focus on steel & stainless steel, study toughness and crack risk	2023
5	Squirrel[16]	Changes in crystal structure and lattice strain in zirconium alloys due to heating	Different materials (zirconium alloys); Researching the conductivity and strain of the lattice	2023
6	Yovial Mahyoedin, Jamasri, Wenny Marthiana, Duskiardi, Rizky Arman[17]	Effect of thermal treatment, stretching, and shot peening on aluminum alloy	Still aluminum, but a common alloy, not ACSR; focus on the effects of mechanical treatment and heating, while you focus on the effects of repeated heating in service conditions.	2020
7	Sugondo, Futichah[18]	Effect of high temperature on residual stress and alloy strain Zr-1%Sn-1%Nb-1%Fe	Focus on special zirconium alloys; Researching residual stress	2007

Yes	Researcher Name	Research Title	Novelties	Year
8	M. Celcilia, I. Syahbanu, and A. B. Aritonang[19]	Effect of heating time on polymerization of composite materials	Different materials (composites); Focus on conductivity & mechanical properties due to heating duration	2021
9	Wilson A. Vasquez, Dilan Jayaweera, Jesus Jativa-Ibarra[20]	*Advanced aging failure model for overhead conductors*	The study introduces an advanced aging failure model for air conductors (OHL) with a comprehensive approach that incorporates the influence of load and weather conditions in the calculation of failure probability,	2017
10	Cuidong Xu, Huiwen Xiao, K. W. E. Cheng[21]	*Reliability and Aging Analysis for Power cables*	In this paper, a method for estimating the service life of power cables under various conditions is proposed, which is based on the Arrhenius model. This model predicts cable life by detecting leakage current and discharge characteristics at various temperatures and humidity.	2022

Conveyor Wire

A conductive wire is designed to conduct electrical current and must have high electrical conductivity and resistance to heat. In air transmission lines, the wire is exposed to environmental factors like heat, rain, wind, and mechanical loads from stretching and tensile forces. Besides conducting electricity, the wire must withstand mechanical stresses, especially in high-voltage overhead lines (SUTT/SUTET), where it faces wind, ice, and tension. High temperatures, caused by overloads, extreme conditions, and Joule heating, can alter the wire's physical and mechanical properties, leading to plastic deformation, loss of tensile strength, and increased resistance.

Konduktor ACSR (Aluminium Conductor Steel Reinforced)

ACSR (Aluminum Conductor Steel Reinforced) is a conductor used in high-voltage, long-distance power transmission systems. It combines aluminum for electrical conductivity and steel for mechanical strength. The conductor consists of a steel core surrounded by aluminum strands, balancing tensile strength and conductivity. This makes ACSR a popular choice for air transmission lines. The following sections cover the specifications, performance, and advancements of ACSR conductors.

Tensile Voltage as a Mechanical Parameter

Tensile strength and elongation are key properties that describe a material's behavior under uniaxial loading, with tensile testing determining properties like Young's modulus, yield strength, and ductility. In cable systems, these properties are influenced by the arrangement of aluminum strands around a steel core and material processing conditions, with advanced methods like finite element modeling providing more precise material characterization.

Arrhenius Method

The Arrhenius method is a mathematical approach used to predict the rate of material degradation due to the influence of temperature over a certain period of time. This model is based on the theory of reaction kinetics, which states that the rate of chemical reactions (including the process of material degradation) increases exponentially as the temperature increases. This principle was stated by Svante Arrhenius at the end of the 19th century and is still widely applied to the analysis of the useful life of electrical equipment, cables, insulators, and conductors.

Effect of Thermal Heating on Mechanical Properties of Materials

Thermal heating, whether intentional through heat treatment or accidental due to high operating temperatures, has a profound and complex influence on the mechanical properties of materials. Temperature changes can modify the microstructure of the material, which in turn affects strength, hardness, ductility, creep resistance, and fatigue resistance. Understanding these interactions is crucial in engineering design to ensure reliable material performance under a wide range of thermal conditions.

Differences in Characteristics of New and Used Conductors

Choosing the right conductor is vital for performance, efficiency, and safety, as new and used conductors differ in long-term performance and reliability. New conductors, like copper or microalloyed aluminum, offer benefits for high-temperature operations, while optimization algorithms help reduce power losses and optimize costs by selecting the most suitable conductor.

METHODOLOGY

Research Design

This research is designed with clear focus and boundaries to ensure measurable and objective-relevant results. The object of the study is Aluminum Conductor Steel Reinforced (ACSR) conductors of the same type and size, which are differentiated into two categories:

1. The ACSR conductor is new, never before used or installed on the transmission network.

2. Used ACSR conductors, taken from existing networks that have been operating in the field.

The treatment was in the form of *thermal aging* at five temperature variations: 90°C, 100°C, 110°C, 120°C, and 130°C, with a treatment duration of 24 hours and 100 hours, respectively.

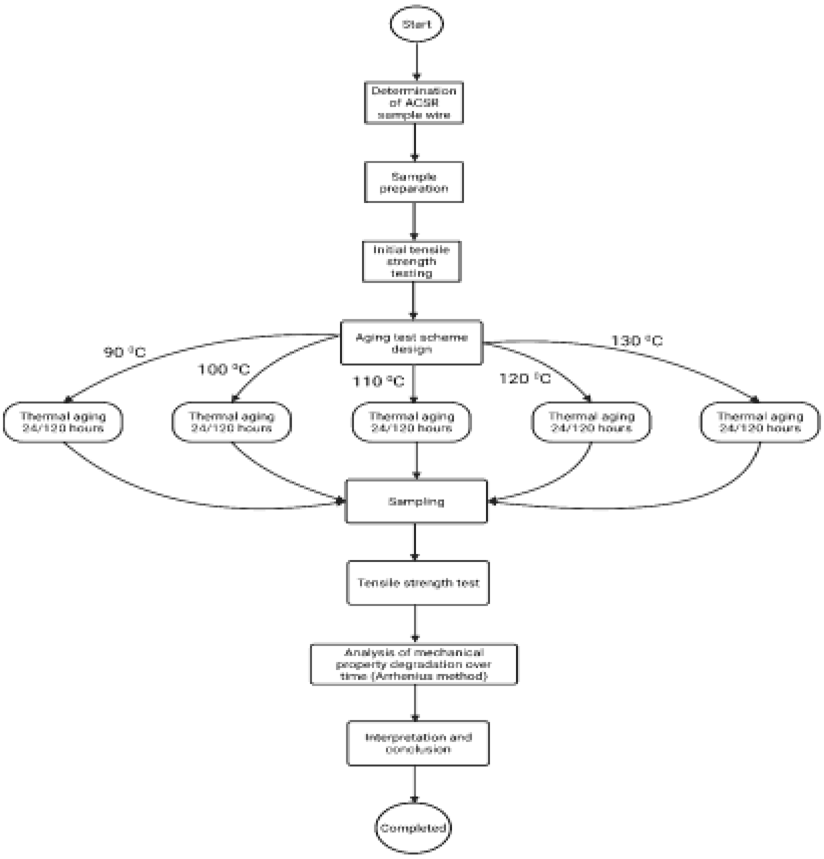

Figure 2. Testing Concept Flowchart

Sample Preparation

The ACSR conductor sample consists of two groups:

1. New ACSR wire, obtained from unused inventory
2. Used ACSR wire, obtained from the existing transmission network as a result of discharge

This study used a total of 260 test wire samples consisting of 130 new ACSR conductor wires and 130 used ACSR conductor wires. The experiment was designed by varying two main factors: aging temperature (90°C, 100°C, 110°C, 120°C, and 130°C) and aging duration (24 hours and 120 hours). The test sample of used conductors was obtained from Palangkaraya which was installed on the Palangkaraya – GI Strait section from 1993.

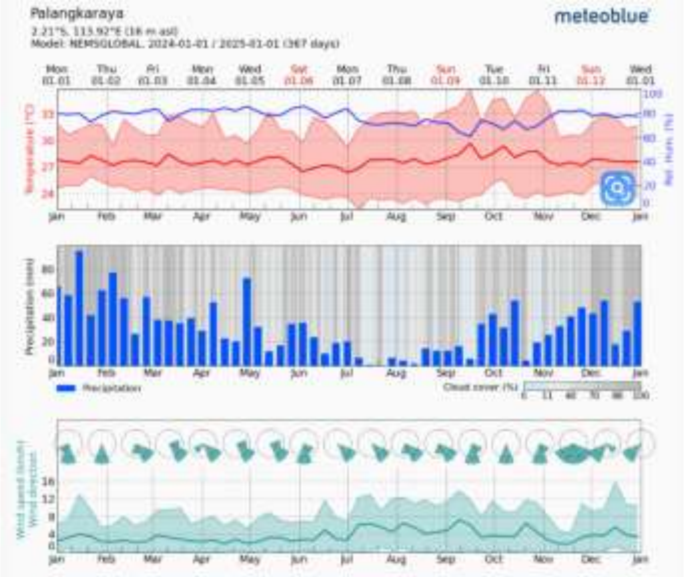

Figure 3. Palangkaraya Annual Climate Chart (2024)

Figure 3 presents the annual weather data for Palangkaraya (1 January 2024 – 1 January 2025). The first graph shows that the air temperature ranges from 24–33 °C, with small fluctuations, indicating a stable tropical climate. Relative humidity stays between 60–80%, rising during the rainy season. The second graph highlights high rainfall at the beginning of the year (January–March), with a dry period from July–September and increased rainfall again from October to December. The third graph shows an average wind speed of 4–12 km/h, with consistent wind direction throughout the year. This data reflects Palangkaraya's equatorial tropical climate, characterized by stable temperatures, high humidity, and distinct wet and dry seasons.

Tabel 2. Number of Test Samples

Jenis	Sample Code	Aging Time	Temperature	Number of Samples	
				Tensile Tension	
				Before Aging	After Aging
New ACSR	BA1-24	24	90	13	13
	BA2-24		100		13
	BA3-24		110		13
	BA4-24		120		13
	BA5-24		130		13
	BA1-120	120	90		13
	BA2-120		100		13
	BA3-120		110		13
	BA4-120		120		13
	BA5-120		130		13
Used ACSR	BE1-24	24	90	13	13
	BE2-24		100		13
	BE3-24		110		13
	BE4-24		120		13

Jenis	Sample Code	Aging Time	Temperature	Number of Samples	
				Tensile Tension	
				Before Aging	After Aging
	BE5-24		130		13
	BE1-120	120	90		13
	BE2-120		100		13
	BE3-120		110		13
	BE4-120		120		13
	BE5-120		130		13
Total				26	260

Table 2. presents a comprehensive experimental design to test the thermal resistance of new and used ACSR conductors through the aging acceleration method. This study used a total of 286 samples consisting of 26 samples for prior aging measurement and 260 samples for after aging measurements. The process of preparing test samples with each sample is cut ±32 cm long according to the needs of the tensile test equipment and given an identification code (type and temperature aging). Measurements using *a digital outside micrometer* that has been calibrated on July 19, 2024 by PT Kaliman with calibration uncertainty of ± 1.1 μm

Thermal Aging Treatment

In this study, thermal aging was conducted to simulate the accelerated aging of ACSR conductors under controlled conditions. A total of 260 conductor samples (130 new and 130 used) were prepared according to ASTM B232/B232M standards. The aging process took place in an air circulation oven with temperatures of 90°C, 100°C, 110°C, 120°C, and 130°C for 24 and 120 hours. Additionally, 26 control samples (13 new and 13 used) were kept without aging treatment as a baseline. The aim was to observe oxidative degradation of aluminum strands and analyze the correlation between aging temperature and reduced mechanical performance.

Mechanical Properties Testing

After undergoing the thermal aging process, all samples of new and used ACSR conductors were tested for mechanical properties using the Karl Frank Model Universal Testing Machine (UTM) with a capacity of 50 kN according to the ASTM B557 standard. The test was conducted at a constant speed of 5 mm/min at a grip distance of 250 mm. The test was carried out with an uncertainty value of ± 0.05 kN from the calibration results that had been carried out on October 24, 2023 by PT Kaliman.

Analysis with the Arrhenius Method

The test results data were comprehensively analyzed using the Arrhenius method to model the thermal degradation kinetics of ACSR conductors. The analysis began by converting tensile strength data into the percentage of degradation relative to the control sample, then determining the degradation rate

(k) at each aging temperature.

Data Analysis

Data analysis in this study was carried out quantitatively, with the aim of determining the effect of heating temperature on the decline in the mechanical properties of new and used ACSR wires, which include maximum tensile stress and elongation.

RESEARCH RESULT

ACSR Conductor Tensile Strength Test Results

Initial Data on New and Used ACSR Conductor Tensile Strength

Table 3. New Conductor Tensile Strength Testing (Baseline)

No.	Diameter							Cross-sectional area	Style when breaking	Tensile strength
	Outer twist layer									
	1	2	3	4	5	6	Rata^2			
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm^2)	(N)	(Mpa)
1	3,434	3,420	3,434	3,448	3,430	3,418	3,431	9,246	2053	222,0
2	3,448	3,423	3,432	3,443	3,440	3,435	3,437	9,278	2002	215,8
3	3,424	3,435	3,422	3,436	3,440	3,417	3,429	9,235	2073	224,5
4	3,431	3,434	3,435	3,426	3,436	3,419	3,430	9,240	2094	226,6
5	3,426	3,441	3,425	3,437	3,440	3,426	3,433	9,256	2084	225,1
6	3,429	3,434	3,444	3,418	3,430	3,436	3,432	9,251	2059	222,6
7	3,417	3,442	3,431	3,428	3,417	3,426	3,427	9,224	1848	200,4
8	3,419	3,428	3,430	3,414	3,433	3,425	3,425	9,213	2083	226,1
1	3,425	3,432	3,430	3,422	3,416	3,412	3,423	9,202	1859	202,0
2	3,411	3,433	3,418	3,414	3,426	3,411	3,419	9,181	2043	222,5
3	3,431	3,430	3,425	3,415	3,424	3,430	3,426	9,219	1941	210,5
4	3,410	3,427	3,409	3,422	3,416	3,411	3,416	9,165	1899	207,2
5	3,425	3,422	3,427	3,416	3,420	3,413	3,421	9,192	1961	213,3

Table 4. Used Conductor Tensile Strength Testing

No	Diameter							Cross-sectional area	Style when breaking	Tensile strength
	Outer twist layer									
	1	2	3	4	5	6	Rata^2			
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm^2)	(N)	(Mpa)
1	3,409	3,439	3,420	3,405	3,413	3,419	3,418	9,176	1487	162,1
2	3,456	3,434	3,438	3,422	3,442	3,431	3,437	9,278	1495	161,1
3	3,488	3,488	3,456	3,410	3,434	3,451	3,455	9,375	1541	164,4
4	3,455	3,458	3,458	3,457	3,444	3,448	3,453	9,364	1573	168,0
5	3,447	3,451	3,447	3,450	3,447	3,446	3,448	9,337	1528	163,6
6	3,453	3,444	3,488	3,442	3,435	3,429	3,449	9,343	1542	165,0
7	3,412	3,418	3,422	3,420	3,415	3,418	3,418	9,176	1554	169,4
8	3,457	3,432	3,496	3,497	3,419	3,445	3,458	9,392	1552	165,3
1	3,451	3,451	3,459	3,457	3,453	3,459	3,455	9,375	1560	166,4
2	3,435	3,472	3,442	3,450	3,445	3,439	3,447	9,332	1541	165,1
3	3,461	3,446	3,464	3,447	3,426	3,457	3,450	9,348	1609	172,1

No	Diameter							Cross-sectional area	Style when breaking	Tensile strength
	Outer twist layer									
	1	2	3	4	5	6	Rata^2			
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm^2)	(N)	(Mpa)
4	3,456	3,450	3,442	3,450	3,448	3,462	3,451	9,354	1574	168,3
5	3,449	3,428	3,452	3,465	3,449	3,456	3,450	9,348	1508	161,3

Table 5. Average Tensile Strength Test Results

Jenis	Tensile Voltage (Mpa)
NEW ACSR	216,81
ACSR USED	165,50

Test Results After Heating Accelerated Thermal Aging

Table 6. Conductor Tensile Strength Test Results

Jenis	Sample	Aging Time	Temperature	Tensile Tension
NEW ACSR	BA1-24	24	90	216,78
	BA2-24		100	216,65
	BA3-24		110	216,40
	BA4-24		120	215,74
	BA5-24		130	214,59
	BA1-120	120	90	216,70
	BA2-120		100	216,40
	BA3-120		110	216,05
	BA4-120		120	215,20
	BA5-120		130	214,00
ACSR USED	BE1-24	24	90	164,50
	BE2-24		100	163,55
	BE3-24		110	157,69
	BE4-24		120	155,03
	BE5-24		130	144,68
	BE1-120	120	90	159,87
	BE2-120		100	157,08
	BE3-120		110	145,67
	BE4-120		120	140,70
	BE5-120		130	110,21

Decrease in Tensile Strength at Various Temperatures and Durations

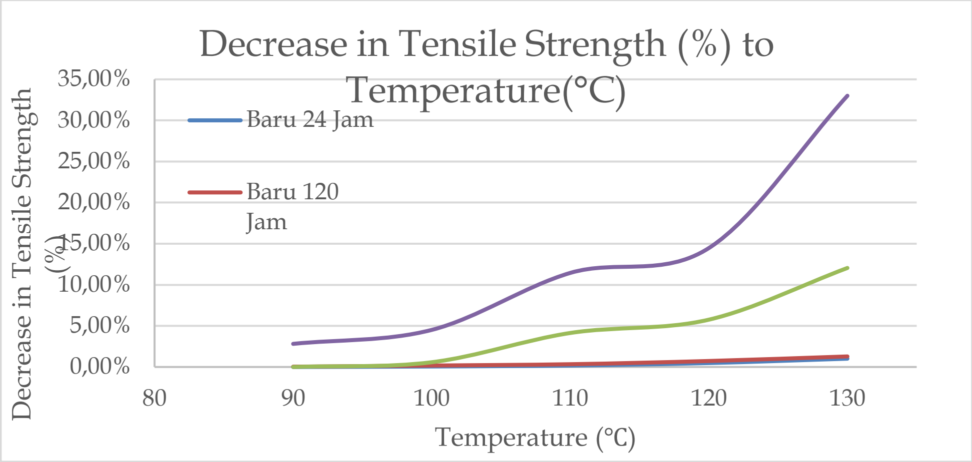

Figure 4. Graph of Decrease in Tensile Strength to Temperature

Material Degradation Analysis with Accelerated Thermal Aging
Relationship of Temperature to Decrease in Tensile Strength

Table 7. Tensile Strength Test Results of New Conductors and Used Conductors

Jenis	**Sample**	**Aging Time**	**Temperature**	**Tensile Tension**	
				Before	**After**
NEW ACSR	BA1-24	24	90	216,81	216,78
	BA2-24		100	216,81	216,65
	BA3-24		110	216,81	216,40
	BA4-24		120	216,81	215,74
	BA5-24		130	216,81	214,59
	BA1-120	120	90	216,81	216,70
	BA2-120		100	216,81	216,40
	BA3-120		110	216,81	216,05
	BA4-120		120	216,81	215,20
	BA5-120		130	216,81	214,00
ACSR USED	BE1-24	24	90	165,50	164,50
	BE2-24		100	165,50	163,55
	BE3-24		110	165,50	157,69
	BE4-24		120	165,50	155,03
	BE5-24		130	165,50	144,68
	BE1-120	120	90	165,50	159,87
	BE2-120		100	165,50	157,08
	BE3-120		110	165,50	145,67
	BE4-120		120	165,50	140,70
	BE5-120		130	165,50	110,21

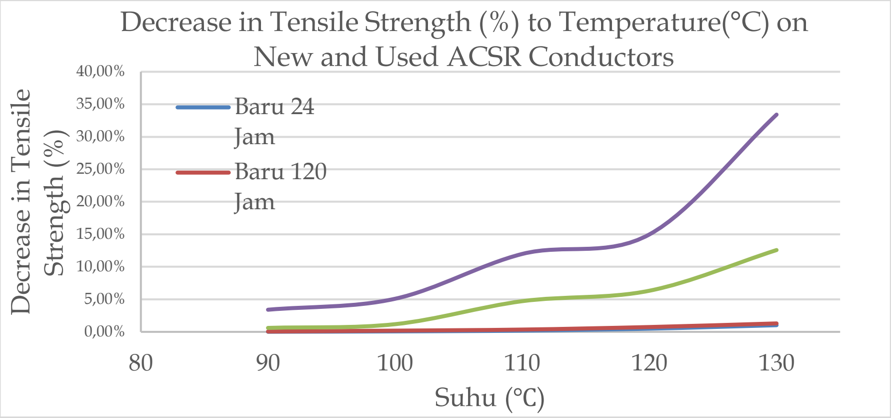

Figure 5. Graph of Decrease in Tensile Strength (%) to Temperature

Tensile Strength to Aging Time Ratio

Table 8. Tensile Strength to Aging Time Ratio

Jenis	Temperature (°)	Racing (%)		Differences
		24 Jam	120 Jam	
NEW ACSR	90	99,99%	99,95%	0,04%
	100	99,93%	99,81%	0,12%
	110	99,81%	99,65%	0,16%
	120	99,51%	99,26%	0,25%
	130	98,98%	98,70%	0,27%
ACSR USED	90	99,39%	96,60%	2,80%
	100	98,82%	94,91%	3,91%
	110	95,28%	88,02%	7,26%
	120	93,67%	85,01%	8,66%
	130	87,42%	66,59%	20,83%

Tensile Strength Decline Curve Visualization

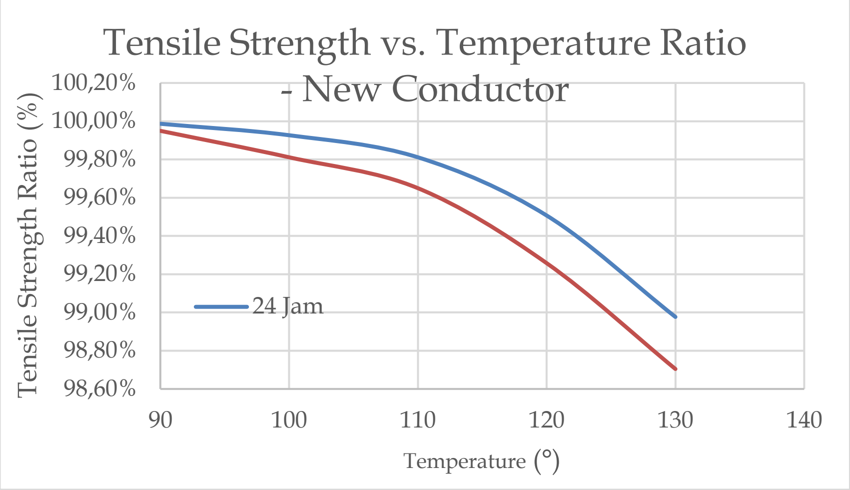

Figure 6. Temperature to Tensile Strength Effect Ratio Curve for New Conductors

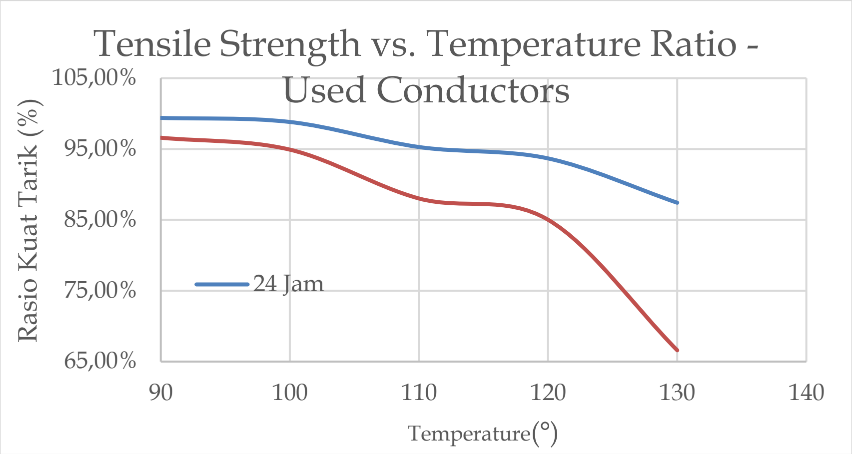

Figure 7. Temperature to Tensile Strength Ratio Curve for Used Conductors

Arrhenius Modeling on Test Data

Table 9. Results of Arrhenius Parameter Calculation

Jenis	Sample	Aging Time	Temperature	Tensile Tension		k	1/T (K^{-1})	ln (k)
				Before	After			
NEW ACSR	BA1-24	24	90	216,81	216,780	0,001208	0,002754	-6,71851
	BA2-24		100	216,81	216,650	0,006625	0,00268	-5,0169
	BA3-24		110	216,81	216,400	0,017042	0,00261	-4,07209
	BA4-24		120	216,81	215,740	0,044542	0,002544	-3,11133
	BA5-24		130	216,81	214,590	0,092458	0,00248	-2,381
	BA1-120	120	90	216,81	216,700	0,000908	0,002754	-7,0039
	BA2-120		100	216,81	216,400	0,003408	0,00268	-5,68153
	BA3-120		110	216,81	216,050	0,006325	0,00261	-5,06325
	BA4-120		120	216,81	215,200	0,013408	0,002544	-4,31188
	BA5-120		130	216,81	214,000	0,023408	0,00248	-3,75466
ACSR USED	BE1-24	24	90	165,50	164,50	0,04175	0,002754	-3,17606
	BE2-24		100	165,50	163,55	0,081333	0,00268	-2,5092
	BE3-24		110	165,50	157,69	0,3255	0,00261	-1,12239
	BE4-24		120	165,50	155,03	0,436333	0,002544	-0,82935
	BE5-24		130	165,50	144,68	0,867583	0,00248	-0,14204
	BE1-120	120	90	165,50	159,87	0,046933	0,002754	-3,05903
	BE2-120		100	165,50	157,08	0,070183	0,00268	-2,65664
	BE3-120		110	165,50	145,67	0,165267	0,00261	-1,80019

BE4-120	120	165,50	140,70	0,206683	0,002544	-1,57657
BE5-120	130	165,50	110,210	0,460767	0,00248	-0,77486

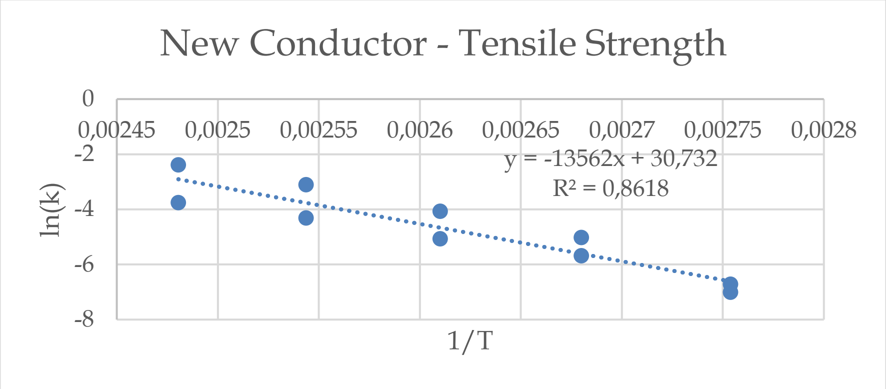

Figure 8. 1/T Linear Regression to New ACSR Conductor Tensile Voltage Log

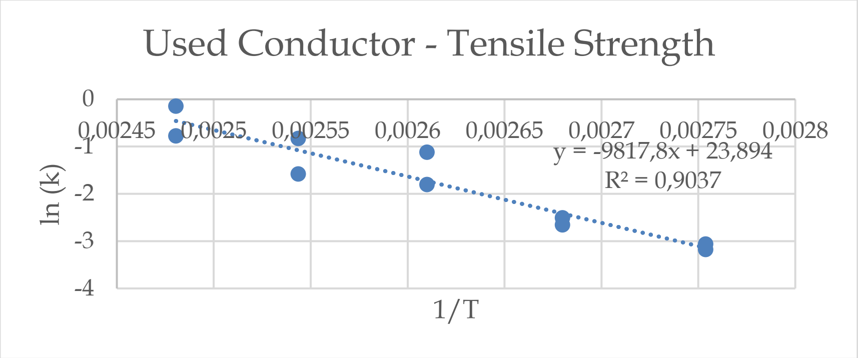

Figure 9. Activation Energy Graph for Used Conductors

Conductor Age Prediction at Operating Temperature

Table 10. Calculation Results of the New Conductor Arrhenius Method

Temperature (°C)	**Temperature (K)**	**1/T**	**k (Mpa/Jam)**	**Age (years)**
75	348,15	0,002872	2.69E-04	42,394
80	353,15	0,002832	4.66E-04	24,422
85	358,15	0,002792	7,97E-04	14,287
90	363,15	0,002754	1.34E-03	8,482
95	368,15	0,002716	2.23E-03	5,108
100	373,15	0,00268	3.65E-03	3,118
105	378,15	0,002644	5.90E-03	1,928
110	383,15	0,00261	9,43E-03	1,208
115	388,15	0,002576	1.49E-02	0,765
120	393,15	0,002544	2.32E-02	0,491
125	398,15	0,002512	3.58E-02	0,318
130	403,15	0,00248	5.46E-02	0,209

Table 11. Calculation Results of the Used Conductor Arrhenius Method

Temperature (°C)	**Temperature (K)**	**1/T**	**k (Mpa/Jam)**	**Age (years)**
75	348,15	0,002872	1.35E-02	0,644
80	353,15	0,002832	2.01E-02	0,432
85	358,15	0,002792	2.96E-02	0,293
90	363,15	0,002754	4.32E-02	0,201
95	368,15	0,002716	6,24E-02	0,139
100	373,15	0,00268	8,92E-02	0,097
105	378,15	0,002644	1.26E-01	0,069
110	383,15	0,00261	1.77E-01	0,049
115	388,15	0,002576	2.47E-01	0,035
120	393,15	0,002544	3.40E-01	0,026
125	398,15	0,002512	4.66E-01	0,019
130	403,15	0,00248	6,32E-01	0,014

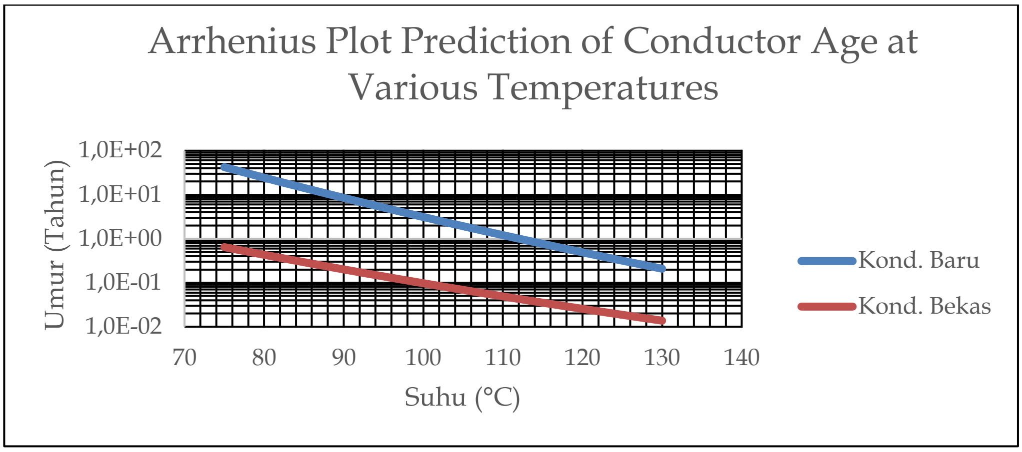

Figure 10. Arrhenius Plot Graph Predicting Conductor Age at Various Temperatures

DISCUSSION

ACSR Conductor Tensile Strength Test Results

Initial Data on New and Used ACSR Conductor Tensile Strength

(Error! No text of specified style in document.-1)

In the initial stages of the study, tensile strength testing was conducted on new and used ACSR conductor samples to establish a baseline value. This baseline will serve as a reference for analyzing degradation due to thermal heating. The cross-sectional area was calculated by measuring the average diameter of the conductor using a specific formula.

$$A = \pi.(\frac{D}{2})^2$$

Were,

A = Cross-sectional Area
π = 3.14
D = Wire Diameter

After obtaining the cross-sectional area, then the tensile strength is calculated using the formula below.

$$Tensile\ Strength = \frac{F}{A}$$ (*Error! No text of specified style in document.*-2)

Were,
F = Maximum Load
A = Cross-sectional Area

Testing is performed according to ASTM B557 standard using *a universal testing machine* (UTM) on a wire cut length of ±320 mm, without prior thermal treatment. The test results can be seen in tables 3, 4, and 5.

Test Results After Heating Accelerated Thermal Aging

Accelerated thermal aging testing was conducted at temperatures of 90°C, 100°C, 110°C, 120°C, and 130°C for 24 and 120 hours on new and used ACSR conductor samples. After heating, the samples were cooled to room temperature and tested for tensile strength. The results showed a trend of decreasing tensile strength with increasing temperature and longer heating duration. However, the new ACSR conductor exhibited only a small decrease in tensile strength, even at high temperatures and extended durations.

Decrease in Tensile Strength at Various Temperatures and Durations

The effect of temperature and heating duration on the tensile strength of ACSR conductors is crucial for assessing their long-term reliability. As the temperature increases, the aluminum and steel components of the conductor undergo microstructural changes, reducing mechanical properties like tensile strength. Figure 4 shows that tensile strength decreases with higher temperatures and longer heating durations. At 130°C for 120 hours, the new conductor's tensile strength dropped by 1.28%, while the used conductor experienced a sharper decrease of 33%. This indicates that used conductors have lower thermal resistance and degrade faster than new conductors.

Material Degradation Analysis with Accelerated Thermal Aging

Relationship of Temperature to Decrease in Tensile Strength

Table 7 shows the relationship between heating temperature and the decrease in tensile strength of conductor material, with testing conducted at temperatures of 90°C to 130°C for 24 and 120 hours. Higher temperatures cause greater decreases in tensile strength due to accelerated oxidation and recrystallization, which weaken the wire. Figure 5 illustrates that at 130°C for 120 hours, used conductors experience a 33.42% decrease in tensile strength, while new conductors show only a 1.30% decrease.

Tensile Strength to Aging Time Ratio

Table 8 shows the tensile strength ratio of new and used ACSR wire after thermal aging at various temperatures and times. Higher temperatures and longer aging times lead to greater decreases in tensile strength, with new ACSR wire maintaining a ratio above 98.7% even at 130°C for 120 hours, while used wire drops to 66.59%. This significant difference highlights how prior exposure to operating conditions accelerates degradation, providing important data for evaluating the durability and service life of ACSR wires, especially in high-temperature environments.

Visualization of Tensile Strength Decline Curve

Figure 6 visualizes the relationship between aging temperature (90°C to 130°C) and the tensile strength ratio of new ACSR conductors after thermal aging. The graph shows a gradual decrease in tensile strength as the temperature increases. At 90°C, the tensile strength ratio is near 100%, but it drops to 98.6% at 130°C, indicating that long-term exposure to high temperatures impacts tensile strength, even in new conductors. This trend aligns with the data in Table 6, where the ratio difference between 24 and 120 hours increases with temperature. In contrast, Figure 7 shows that used ACSR conductors experience a more significant decrease in tensile strength, especially at higher temperatures (≥120°C). At 130°C for 120 hours, the tensile strength ratio drops to 66%, indicating faster degradation due to oxidation, recrystallization, and damage to microstructures formed over time.

Arrhenius Modeling on Test Data

Arrhenius modeling is used to predict the degradation rate of conductor materials due to thermal heating at various temperatures. The model relates temperature to the time of failure or performance degradation through the Arrhenius equation. In this study, the model was applied to evaluate the tensile strength data of ACSR conductors after high-temperature treatment for both new and used conditions. The process involves converting time (age) data into a natural logarithmic form (ln(k)) and temperature into Kelvin units to obtain 1/T. Linear regression analysis is then performed on the ln(k) vs. 1/T graph to calculate the line gradient. The Arrhenius parameters calculated are shown in Table 9. The gradient is directly related to the activation energy (Ea), according to the Arrhenius equation:

$$ln(k) = \ln(A) + (\frac{Ea}{R}.\frac{1}{T})$$

(***Error! No text of specified style in document.***-3)

With R is a universal gas constant (8.314 J/mol · K), then the activation energy is calculated as:

$$Ea = Slope\ x\ R$$

(***Error! No text of specified style in document.***-4)

The Ea value indicates the energy required to cause mechanical degradation in a conductor due to temperature. Figure 8 shows a strong relationship between temperature and degradation rate for new ACSR conductors, with an activation energy (Ea) of 112.73 kJ/mol, calculated from the slope of the linear regression line. Figure 9 displays similar data for used ACSR conductors, with an activation energy of 81.61 kJ/mol, lower than that of the new conductor, indicating that used conductors require less energy to degrade.

Conductor Age Prediction at Operating Temperature

The decrease in tensile strength due to thermal exposure is used to predict the aging of both new and used conductors, employing a minimum tensile strength limit and the Arrhenius model. This model establishes a relationship between the degradation rate and temperature, allowing for the extrapolation of short-term data to predict long-term performance. For example, XLPE cables operating at 90°C show a significantly shorter lifespan compared to those at 70°C, with the predicted lifespan at 90°C being 32.2 years. In this study, the Arrhenius model was applied to both new and used conductors to estimate their service life under different temperatures. The results, shown in Table 10, display the relationship between temperature (°C) and predictive age (years) on a logarithmic scale. The Arrhenius plot demonstrates that as the temperature increases, the conductor's lifespan decreases exponentially, with used conductors experiencing a more significant reduction in lifespan than new conductors.

At 100°C, the lifespan of new conductors is predicted to be 10 times longer than used conductors, and this gap widens at higher temperatures. These findings emphasize that used conductors degrade faster due to previous environmental exposure. The plots generated help determine conductor replacement intervals, highlighting the importance of stricter inspections for used conductors, particularly those operating above 90°C, to prevent premature failure. Existing research indicates that aluminum conductors begin losing mechanical strength above 93°C, which increases the probability of failure and reduces safety margins. Furthermore, environmental factors, such as corrosion in copper cables, accelerate degradation, making regular inspections essential for conductors operating at temperatures above 90°C. High temperatures also exacerbate sagging, reduce tensile strength, and accelerate aging of connection connectors in ACSR conductors, which in turn increases resistivity and weakens clamping strength, potentially jeopardizing the integrity of the power transmission network.

CONCLUSIONS AND RECOMMENDATIONS

Thermal aging testing on ACSR conductors revealed a significant difference between new and used conductors. In new ACSR, tensile strength decreased only slightly, by 1.3% after 120 hours at 130°C, showing good resistance to thermal aging. In contrast, used ACSR saw a drastic decrease of 33.4% under the same conditions, indicating that prior usage leads to microstructural degradation. Using the Arrhenius method, the lifespan of new conductors ranges from 42.4 years at 75°C to 0.21 years (2.5 months) at 130°C. For used conductors, the lifespan is much shorter, from 0.97 years at 75°C to 0.014 years (5 days) at 130°C. The increase in temperature from 75°C to 130°C reduced the lifespan of new conductors by about 99.72% and used conductors by 98.56%. At 100°C, new conductors last around 3.86 years, while used conductors last only about 1 month. The degradation rate (k) increases exponentially with temperature, showing that high operating temperatures accelerate conductor deterioration. Therefore, the reuse of used ACSR conductors is not recommended due to significant tensile strength loss, especially in high temperatures. Even at lower temperatures (<90°C), degradation still affects reliability. To ensure safety and reliability, new conductors should be used, and if used conductors are considered, strict technical requirements and a condition-based maintenance program should be implemented.

ADVANCED RESEARCH

1. This study did not cover the electrical properties of ACSR conductors (such as conductivity or resistance) after thermal heating treatments, unless they are directly related to mechanical properties.
2. This study did not discuss the analysis of corrosion, fatigue due to wind vibration (aeolian vibration), and other environmental factors that can affect conductor degradation.
3. The research was conducted in a controlled laboratory setting using samples, and did not include field tests on the actual transmission network.

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