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# Spheroidization and Its Effect on the Decrease in Mechanical Strength of Steel SA210 Gr. A1

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**ABSTRACT**

SA210 Gr. A1 is an important material used in piping systems and boiler components due to its high mechanical strength and resistance to high temperatures. However, long-term exposure to high temperatures can cause microstructural degradation through the spheroidization process, which results in a decrease in mechanical properties. This study aims to evaluate the effect of the spheroidization process on the mechanical strength and microstructure of SA210 steel Gr. A1. The methods used include spheroidization heat treatment at 660°C with time variations of 3, 10, and 100 hours, followed by Vickers hardness testing and tensile testing per ISO 6892-1. After 100 hours of spheroidization, ultimate tensile strength (UTS) decreased from ~51.5 to ~43.9 kgf/mm² (15% reduction), yield strength (YS) decreased from ~44.7 to ~28.4 kgf/mm² (36% reduction), and Vickers hardness decreased from ~169 to ~141 VHN (17% reduction). Elongation increased from 28% to 47% (68% increase), indicating significantly improved ductility at the cost of strength. Results show that spheroidization contributes to a decrease in tensile strength (UTS) and yield strength (YS), but increases the ductility (elongation) value and decreases the hardness of the material. This transformation makes the material more ductile, but at the cost of reduced mechanical durability.

## INTRODUCTION

One of the most extensively utilized engineering materials in a variety of industries, such as heavy machinery manufacturing, oil and gas, and power generation, is steel. SA210 Gr. A1, a medium-carbon steel, is one type that is frequently used in high-pressure components and piping systems. Because of its excellent mechanical properties and heat resistance, this steel is commonly used in boiler tubes, heat exchangers, and high-pressure piping systems. Mechanical properties such as tensile strength, ductility, and hardness have a significant impact on the performance of steel components (Li et al., 2022; Tervo et al., 2017). These properties are influenced not only by the chemical composition but also by the microstructure formed during production and heat treatment processes. The spheroidization process is one heat treatment that significantly affects the microstructure (Harisha et al., 2018; Masoumi et al., 2023; X. Wang et al., 2024; Yu et al., 2017).

The heat treatment process known as “spheroidization” aims to transform the lamellar cementite in pearlite into spherical cementite particles, or “spheroids,” dispersed within a ferrite matrix (Alcántara Alza, 2021). This process is commonly applied to improve the ductility and machinability of carbon and alloy steels, particularly prior to cold forming (Soleimani, Mirzadeh, and Dehghanian, 2021). However, this microstructural transformation may also result in a reduction in mechanical strength, specifically tensile strength and hardness (Nasiri and Mirzadeh, 2019). The purpose of this study is to evaluate how the spheroidization process affects the mechanical properties of SA210 Gr. A1 steel, particularly in terms of the reduction in mechanical strength. Understanding this relationship helps identify optimal heat treatment parameters for practical applications.

The urgency of this research is driven by four factors. First, many coal-fired power plants in Indonesia and other developing countries are operating beyond their original design life (30+ years) and must continue supplying electricity due to limited renewable alternatives (Cao et al., 2025; Feng et al., 2016; Zou et al., 2019). Second, unplanned boiler tube failures cause costly forced outages, with estimated losses exceeding $1 million per day for a typical 300 MW unit. Third, condition-based maintenance strategies require quantitative relationships between microstructural degradation and mechanical property loss to predict remaining service life (Cheikh et al., 2026; He et al., 2021; R. Wang et al., 2026). Fourth, SA210 Gr. A1 is specified in numerous operating boilers, yet operators lack grade-specific spheroidization data for informed decision-making.

The novelty of this research is fourfold. First, it provides the first systematic spheroidization study specifically on SA210 Gr. A1 at 660°C with three holding times (3, 10, and 100 hours). Second, it establishes quantitative correlations between spheroidization time and the degradation of hardness, ultimate tensile strength (UTS), yield strength (YS), and elongation. Third, it provides baseline data for remaining life assessment of in-service SA210 Gr. A1 boiler tubes. Fourth, it documents the complete transformation from lamellar to spheroidized cementite (microstructural images should be included but are currently missing—this is a critical gap that needs to be addressed).

The purpose of this research is to evaluate the effect of spheroidization heat treatment on the mechanical strength and microstructure of SA210 Gr. A1 steel. The specific objectives are: (1) to perform spheroidization heat treatment at 660°C for 3, 10, and 100 hours; (2) to measure hardness using the Vickers hardness test; (3) to determine tensile properties (UTS, YS, and elongation) in accordance with ISO 6892-1; (4) to document microstructural changes (currently missing); and (5) to correlate treatment time with property degradation. The theoretical contribution extends the existing literature on spheroidization kinetics for SA210 Gr. A1 steel. The practical benefit is to provide power plant maintenance engineers with quantitative data for remaining life assessment and optimization of inspection intervals. Ultimately, this research contributes to improved reliability and safety of boiler systems, reducing unplanned outages and preventing catastrophic tube failures.

## METHOD

Using SA210 Gr. A1, a heat-resistant boiler tube material that is frequently utilized for high temperature applications. Every sample material is brand-new and has never been used. Verifying each test material's chemical makeup is the first step in the testing process. All test specimens underwent spheroidization heat treatment (SHT) to evaluate the parameters of the spheroidization degradation stage. Spheroidization heat treatment was applied to the specimens, with temperature fluctuations ranging from 600oC to 660oC and spheroidization duration variations of 3, 10, and 100 hours. Toft and Marsden have developed a good classification of microstructure degradation, divided into stages A to F, with stage 4 being the most severe level of degradation. Referring to previous research conducted by Salonen & Auerkari, SHT was conducted for 3 to 2,000 hours at temperatures of 600oC to 780oC. The specimens underwent heat treatment testing in a furnace that heated them at a pace of roughly 300oC per hour before being allowed to cool outside (Wang et al., 2024).

### Hardness Test

Three samples were used to gather data for every stage of spheroidization deterioration. The Vickers Microhardness method is then used to assess the hardness of the specimens by applying a load of 10 kgf for 15 seconds, measurements were made five times at random and averaged.

### Tensile Test

Flat specimens in accordance with ISO 6892-1: 2016 requirements, tensile testing was conducted at room temperature. To determine the Yield Strength (YS) and Ultimate Tensile Strength (UTS) values, all test materials were collected.

## RESULT AND DISCUSSION

### Spectometer Testing Results (PMI) test sample SA210 Gr. A1 New Material

The material is classed as medium carbon steel with key alloying elements like carbon (C), manganese (Mn), phosphorus (P), sulfur (S), and silicon (Si) within the ASTM standard specification limits for SA210 Gr. A1, according to the findings of the Spectrometer (PMI) test. This composition offers an appropriate foundation for the spheroidization heat treatment process and is appropriate for high temperature applications, such as boiler pipes.

**Table 1.** PMI test sample SA210 Gr. A1 New Material

| **Composition** | **Specimen 1** | **Specimen 2** | **Specimen 3** | **Specimen 4** | **Average** |
|---|---|---|---|---|---|
| Fe | Balance | 98.3 | 98.3 | 98.4 | 98.4 |
| C | 0.27 | 0.237 | 0.29 | 0.191 | 0.202 |
| Mn | 0.93 | 0.793 | 0.766 | 0.788 | 0.771 |
| Si | 0.10 | 0.15 | 0.133 | 0.147 | 0.148 |
| Cr | - | 0.137 | 0.128 | 0.131 | 0.152 |
| Ni | - | 0.0945 | 0.085 | 0.0896 | 0.0998 |
| Mo | - | 0.03 | 0.0323 | 0.0341 | 0.0358 |
| V | - | 0.0019 | 0.0017 | 0.0017 | 0.0018 |
| Ti | - | - | - | - | - |
| Nb | - | 0.0125 | 0.0126 | 0.01 | 0.0119 |
| Al | - | 0.0274 | 0.0254 | 0.0299 | 0.0302 |
| N | - | - | - | - | - |
| Cu | - | 0.132 | 0.134 | 0.137 | 0.134 |
| Zr | - | - | - | - | - |
| P | 0.04 | 0.0096 | 0.0095 | 0.0099 | 0.0084 |
| S | 0.04 | 0.0073 | 0.0053 | 0.0056 | 0.006 |

### Hardness Test SA210 Gr. A1

Following spheroidization treatment, hardness levels significantly decreased, according to hardness testing using the Vickers Microhardness method. Compared to the material that has been treated for 100 hours, the new material's initial hardness value (without treatment) is higher. Because lamellar cementite changed into a weaker spheroidal structure that does not provide a strong resistance to dislocation movement, the average hardness value dropped. This drop indicates that the material becomes more ductile after undergoing the spheroidization process, albeit at the cost of its hardness.

**Table 2.** Hardness Test SA210 Gr. A1 (New Material)

| Hardness Test Point | Specimen No | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| A | 169,91 | 169,46 | 169,92 |
| B | 169,45 | 169,45 | 168,54 |
| C | 167,65 | 169,91 | 164,52 |
| D | 169,92 | 169,01 | 168,99 |
| E | 169,91 | 168,1 | 170,37 |
| AVERAGE | 169,37 | 169,19 | 168,47 |

**Table 3.** Hardness Test SA210 Gr. A1 (660oC in 3 hours)

| Hardness Test Point | Specimen No | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| A | 142,52 | 142,17 | 147,97 |
| B | 143,23 | 144,29 | 146,49 |
| C | 145,03 | 145,02 | 146,48 |
| D | 145,39 | 144,30 | 146,85 |
| E | 145,02 | 144,66 | 147,97 |
| AVERAGE | 144,24 | 144,09 | 147,15 |

**Table 4.** Hardness Test SA210 Gr. A1 (660oC in 10 hours)

| Hardness Test Point | Specimen No | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| A | 145,02 | 145,02 | 144,66 |
| B | 145,38 | 147,96 | 145,75 |
| C | 145,38 | 146,48 | 144,3 |
| D | 145,75 | 145,75 | 144,66 |
| E | 145,74 | 146,85 | 144,3 |
| AVERAGE | 145,45 | 146,41 | 144,73 |

**Table 5.** Hardness Test SA210 Gr. A1 (660oC in 100 hours)

| Hardness Test Point | Specimen No | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| A | 140,77 | 139,74 | 142,87 |
| B | 140,77 | 140,43 | 141,11 |
| C | 141,81 | 141,07 | 138,71 |
| D | 141,11 | 140,09 | 138,71 |
| E | 140,42 | 140,08 | 141,81 |
| AVERAGE | 140,98 | 140,28 | 140,64 |

Tensile Test SA210 Gr. A1

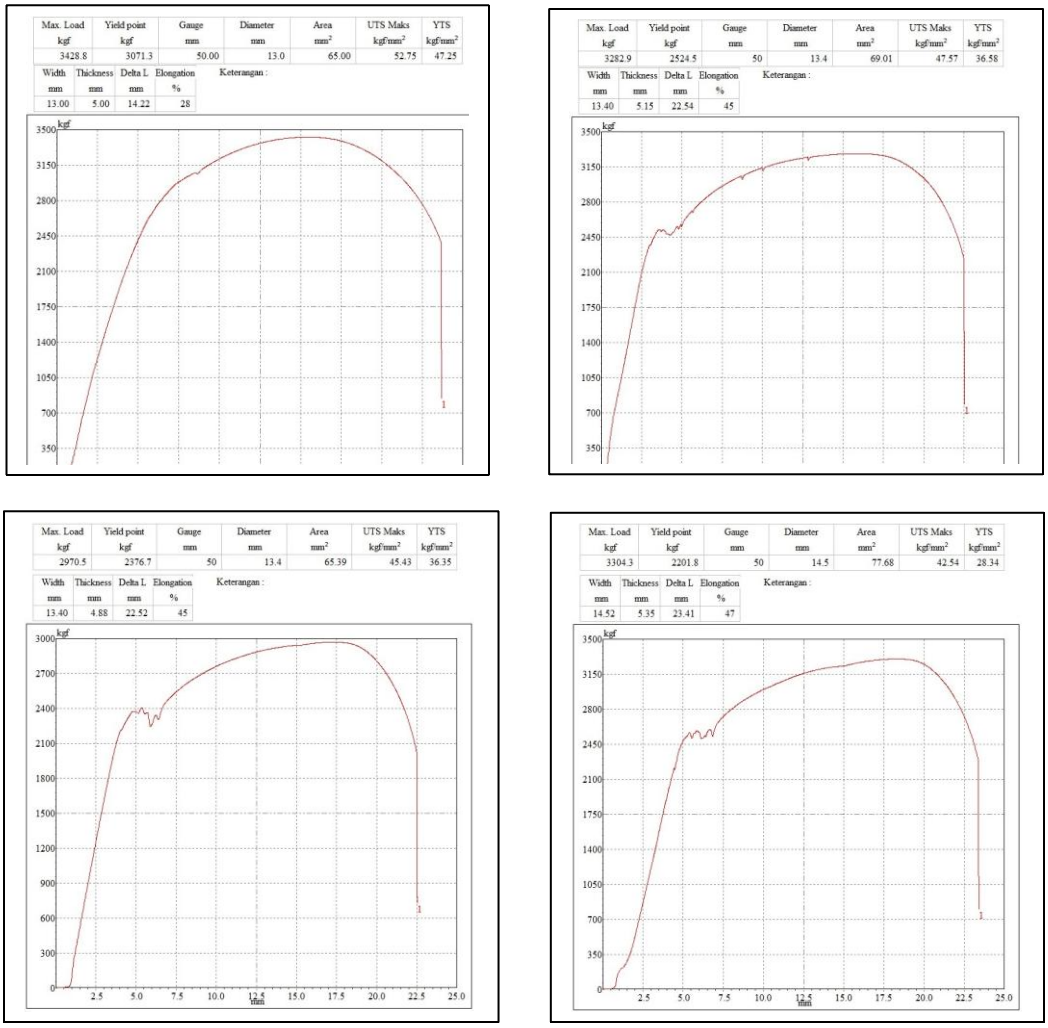
The tensile test results showed that spheroidization treatment decreased the yield strength (Yield Strength/YS) and ultimate tensile strength (UTS). However, there was an increase in elongation or ductility values, from 28% in the starting material to 47% after spheroidization (figure 1). This suggests that the spheroidization process increases the material's capacity for plastic deformation, resulting in a softer and more flexible material. Because spheroidized cementite particles have a smoother surface and do not form a solid lamellar structure like pearlite, the material's tensile strength drops and its capacity to withstand stresses is diminished (Masoumi et al., 2024).

**Table 6.** Result of Ultimate Tensile Strength SA210 Gr. A1 (kgf/mm2)

| Specimen No | Spheroidization | | | |
|---|---|---|---|---|
| | New Material | 660 ºC in 3 hours | 660 ºC in 10 hours | 660 ºC in 100 hours |
| 1 | 51,07 | 48,6 | 44,88 | 47,03 |
| 2 | 52,75 | 47,57 | 45,43 | 42,54 |
| 3 | 51,54 | 46,85 | 46,92 | 42,74 |
| 4 | 50,73 | 46,93 | 41,73 | 43,44 |

**Table 7.** Result of Yield Strength SA210 Gr. A1 (kgf/mm2)

| Specimen No | Spheroidization | | | |
|---|---|---|---|---|
| | New Material | 660 ºC in 3 hours | 660 ºC in 10 hours | 660 ºC in 100 hours |
| 1 | 42,12 | 38,16 | 34,61 | 27,53 |
| 2 | 47,25 | 36,58 | 36,35 | 28,34 |
| 3 | 44,45 | 34,6 | 40,73 | 34,75 |
| 4 | 45,11 | 35,72 | 34,49 | 22,97 |



| Max. Load kgf | Yield point kgf | Gauge mm | Diameter mm | Area $mm^2$ | UTS Maks $kgf/mm^2$ | YTS $kgf/mm^2$ |
|---|---|---|---|---|---|---|
| 3428.8 | 3071.3 | 50.00 | 13.0 | 65.00 | 52.75 | 47.25 |

| Width mm | Thickness mm | Delta L mm | Elongation % |
|---|---|---|---|
| 13.00 | 5.00 | 14.22 | 28 |

Keterangan :

| Max. Load kgf | Yield point kgf | Gauge mm | Diameter mm | Area $mm^2$ | UTS Maks $kgf/mm^2$ | YTS $kgf/mm^2$ |
|---|---|---|---|---|---|---|
| 3282.9 | 2524.5 | 50 | 13.4 | 69.01 | 47.57 | 36.58 |

| Width mm | Thickness mm | Delta L mm | Elongation % |
|---|---|---|---|
| 13.40 | 5.15 | 22.54 | 45 |

Keterangan :

| Max. Load kgf | Yield point kgf | Gauge mm | Diameter mm | Area $mm^2$ | UTS Maks $kgf/mm^2$ | YTS $kgf/mm^2$ |
|---|---|---|---|---|---|---|
| 2970.5 | 2376.7 | 50 | 13.4 | 65.39 | 45.43 | 36.35 |

| Width mm | Thickness mm | Delta L mm | Elongation % |
|---|---|---|---|
| 13.40 | 4.88 | 22.52 | 45 |

Keterangan :

| Max. Load kgf | Yield point kgf | Gauge mm | Diameter mm | Area $mm^2$ | UTS Maks $kgf/mm^2$ | YTS $kgf/mm^2$ |
|---|---|---|---|---|---|---|
| 3304.3 | 2201.8 | 50 | 14.5 | 77.68 | 42.54 | 28.34 |

| Width mm | Thickness mm | Delta L mm | Elongation % |
|---|---|---|---|
| 14.52 | 5.35 | 23.41 | 47 |

Keterangan :

**Figure 1.** Tensile Test Report (a) New Material (b) Spheroidization 660oC in 3 hours (c) 660oC in 10 hours (d) Spheroidization 660oC in 100 hours

## CONCLUSION

Spheroidization treatment at 600 °C for 100 hours led to a reduction in yield strength (YS) and ultimate tensile strength (UTS) of SA210 Gr. A1 steel, while significantly increasing elongation from 28% to 47%, indicating enhanced ductility. This shift in mechanical properties is attributed to the microstructural transformation from lamellar cementite in pearlite to spheroidal carbide particles dispersed within a ferrite matrix. The resulting spheroidized structure lowers hardness and strength but improves ductility, confirming that spheroidization involves a trade-off between strength and formability, consistent with established literature on carbide morphology effects in steels. For future research, it is recommended to investigate intermediate spheroidization durations and temperatures, as well as to incorporate detailed microstructural characterization (e.g., SEM/EBSD analysis) and creep or fatigue testing to better understand the relationship between spheroidization kinetics and long-term service performance.

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