

# Strength Analysis of Welded Joints on the Side of a Railway Bogie Frame with Variations in Welding Speed Using the Finite Element Method

<sup>1</sup>\*Ojo Kurdi, <sup>2</sup>Achmad Widodo, <sup>3</sup>MSK Tony Suryo Utomo, <sup>4</sup>Mochamad Cahyo Adi Nugroho

<sup>1,2,3,4</sup>Faculty of Engineering, Department of Mechanical Engineering, Diponegoro University, Indonesia

\*Corresponding Author's E-mail: [ojokurdi@ft.undip.ac.id](mailto:ojokurdi@ft.undip.ac.id)

**Abstract** - The development of Electric Multiple Units (EMU/KRL) as environmentally friendly transportation requires a reliable and structurally safe bogie system. One critical aspect of the bogie side frame is the quality of its welded joints, which directly affects structural integrity and operational safety. This study investigates the strength and performance of welded joints on a railway side frame by varying the Gas Metal Arc Welding (GMAW) travel speed using ER70S-6 filler metal on 12.5 mm SS400 steel. An integrated experimental–numerical approach was applied. Butt-joint specimens were prepared according to ASTM E8/E8M to obtain tensile strength, strain, elastic modulus, density, and Poisson's ratio at travel speeds of 10, 15, 20, 25, and 30 cm/min. These mechanical properties were used as material inputs and validation parameters for the Finite Element Method (FEM) model. The welded region of the side frame was simulated in ANSYS Workbench under four service load scenarios: vertical static, traction, braking, and lateral (cornering). Structural responses including von Mises stress, total deformation, and safety factor were evaluated at critical welded interfaces, namely the web–liner/cover and web–top plate joints. Both experimental and FEM results exhibit consistent trends showing that travel speed influences the strength–ductility balance and stress distribution within the side frame structure. The 20 cm/min travel speed condition was selected as the primary validated case, while 15 and 25 cm/min were used for comparison. The findings highlight the importance of travel speed control in ensuring weld quality and supporting the structural reliability of railway bogie side frames.

**Keywords:** Bogie Side Frame, Finite Element Method (FEM), GMAW, Tensile Strength, Welding Travel Speed.

## I. INTRODUCTION

In railway engineering, the bogie side frame serves as one of the most critical structural components responsible for supporting static and dynamic loads during the operation of

Electric Multiple Units (EMU/KRL). The structural integrity of this component is strongly influenced by the quality of its welded joints, which must comply with safety, durability, and manufacturing standards. Recent studies have emphasized that improper welding parameters can increase residual stress, reduce joint strength, and lead to premature structural deformation that may compromise operational safety [1]. Although welding standards such as AWS D1.1 and JIS Z 3150 have been widely implemented, variations in heat input resulting from different travel speeds remain a major challenge in ensuring consistent weld quality for railway applications [2].

Previous research has largely examined the effect of welding parameters on the mechanical properties of welded joints through experimental testing. For example, several studies reported that variations in heat input significantly alter microstructure formation, tensile strength, and ductility in low-carbon steel welds. Similarly, travel speed has been shown to affect bead geometry, penetration depth, and hardness distribution, making it a key parameter in GMAW processes. However, most of these investigations focus solely on specimen-level testing and do not extend to component-level structural analysis, particularly under complex multi-directional loading conditions that occur in railway bogie operations [3]. Despite these findings, the current literature still lacks integrated studies that combine mechanical experiments with numerical simulations to evaluate how welding parameter variations influence the global behavior of an actual bogie side frame structure [4][5].

This study aims to address this research gap by developing a combined experimental–numerical approach to analyze the effect of welding travel speed on the mechanical performance of SS400 welded joints and the structural response of a bogie side frame. Mechanical testing was carried out on butt-joint specimens welded using the GMAW process with ER70S-6 filler metal at travel speeds of 10, 15, 20, 25, and 30 cm/min. The resulting tensile strength, elongation, Young's modulus, density, and Poisson's ratio were then used as input and validation parameters for a finite element model of

the side frame. Through numerical simulations conducted in ANSYS Workbench, the welded regions were evaluated under four service loading conditions: vertical static loading, traction, braking, and lateral (cornering) forces. By gaining a deeper understanding of how travel speed affects both local weld behavior and global structural performance, this research is expected to contribute to improved welding quality control and provide a scientific basis for enhancing the structural reliability of bogie side frames under operational conditions[6][7].

## II. RESEARCH METHODOLOGY

The methods used to collect data and analyze the stress behavior of welded joints on the side frame of a railway bogie considering variations in welding speed and filler metal are described as follow:

### 1) Observation

Direct observations were carried out at the fabrication area where the side frame of the railway bogie is manufactured. The focus of the observation included the actual welding process using GMAW (Gas Metal Arc Welding), the preparation of butt joint specimens, visual inspection of weld quality, and the actual loading conditions experienced by the side frame during operation (static vertical load, acceleration, braking, and lateral loads during curving).

### 2) Literature Study

The literature study involved an extensive review of welding standards, scientific journals, engineering textbooks, and technical documents related to welded joint behavior and structural analysis. This review included AWS D1.1 guidelines for structural welding, previous research on the influence of welding speed on GMAW weld quality, and studies applying the Finite Element Method to railway bogie structures. Additional references on material properties, heat input calculation, and stress evaluation criteria were also examined to establish a strong theoretical foundation for the analysis.

## 2.1 Primary Data

Primary data were obtained through field observations, welding activities, tensile testing, and finite element simulations conducted during the research. These data served as the basis for modeling and validating the structural performance of the welded joints on the railway bogie side frame. The types of primary data include:

### 1) Specifications

The specifications of the side frame used in this research were obtained from the actual railway bogie technical

drawings. These specifications provide dimensional references and structural characteristics needed for CAD modeling and FEM simulation.

**Table 1: Side Frame Bogie Specifications**

Parameter	Value (mm)
Width of bogie frame	2240
Bogie wheel base	2560
Bogie length	3534
Bogie width	3030

**Table 2: H-Beam Profile Dimension for SWL 150 Ton**

Parameter	Value
Material	SS400
Thickness	12 mm
Length	150 mm
Width	200 mm
Groove Type	Single V Groove
Bevel Root Gap	2 mm
Bevel	Yes

**Table 3: Welding Parameters**

Parameter	Value
Welding Current (A)	150
Welding Voltage (V)	25
Travel Speeds (cm/min)	10, 15, 20, 25, 30
Shielding Gas	Ar-CO <sub>2</sub> (80/20) — 15 L/min
Wire Diameter	1.0 mm (ER70S-6)

**Table 4: Specimen Dimensions (ASTM E8/E8M)**

Parameter	Symbol	Value
Gauge Length	G	57 mm
Width	W	12.5 mm
Thickness	T	12.5 mm
Radius of Fillet	R	12.5 mm
Overall Length	L	200 mm
Grip Length	A	50 mm
Grip Width	C	20 mm

**Table 5: Tensile Test Results**

Parameter	Value
Modulus of Elasticity (GPa)	200
Yield Strength (MPa)	365
Ultimate Strength (MPa)	440
Elongation (%)	35.35
Fracture Location	HAZ

**Table 6: Load case EN 13479**

Load Case	Vertical [N]	Longitudinal Shunt/Dec./Yaw [N]	Longitudinal Gearbox [N]	Braking [N]	Transversal [N] Bump Stop	Transversal [N] Air Spring
1	128070	*	*	*	*	*
2	128070	*	*	*	89.678	4.401
3	128070	176.580	*	*	*	*
4	128070	32.973	*	-50700	*	*

clearer path for iterative structural assessment and design validation.

A mathematical and simulation-based analysis was also conducted using the Finite Element Method (FEM). A detailed CAD model of the bogie side frame and its welded joints was developed, and structural simulations were performed in ANSYS Workbench to evaluate stress distribution, deformation, and safety factors under four operational load conditions. These numerical computations served as a theoretical benchmark for validating the mechanical behavior obtained from tensile testing of SS400-ER70S-6 welded specimens at various welding travel speeds.

1) Von Mises Stress ( $\sigma_v$ )

$$\sigma_v = \sqrt{\frac{(\sigma_x - \sigma_y)^2 + (\sigma_x - \sigma_z)^2 + (\sigma_y - \sigma_z)^2}{2} + 3(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{xz}^2)}$$

2) Safety Factor ( $n$ )

$$n = \frac{S_y}{\sigma_v}$$

3) Stress

$$\sigma = \frac{F}{A}$$

4) Strain

$$\epsilon = \frac{\Delta L}{L_0}$$

5) Modulus of Elasticity

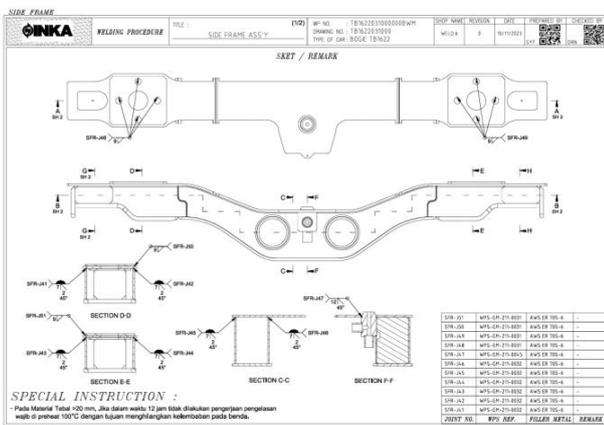
$$E = \frac{\sigma}{\epsilon}$$

6) Welding Heat Input (HI)

$$HI = \frac{V \times I \times 60}{TS}$$

2) Side Frame Bogie Design Drawing

Design drawings refer to the technical visual representation of the spreader bar components and configurations.



**Figure 1: Side Frame Bogie Design**

2.2 Problem Identification and Analysis

The problem identification process focused on evaluating potential structural issues in the welded joints of the bogie side frame such as excessive deformation, stress concentration, reduced safety factor, and strength variations due to different welding speeds by reviewing design documents, inspecting weld quality, developing detailed CAD geometry, and performing FEM simulations under four operational load cases to determine critical regions and validate the structural performance. This flow-based diagnostic method provided a

III. RESULTS AND DISCUSSIONS

3.1 Modelling and Simulation

The geometric model of the railway bogie side frame including the welded joint region connecting the structural members was created using CAD software (SolidWorks). The model was developed based on the actual dimensional specifications of the bogie frame and weld joint configuration obtained from fabrication data. The CAD model was then imported into ANSYS Workbench to perform numerical

simulations using the finite element method (FEM). The simulation process included:

- 1) Meshing: Tetrahedral solid elements were applied with global and body sizing controls to ensure fine and accurate mesh distribution, especially in critical areas.
- 2) Boundary constraints were assigned at the axle box supports and frame connection points to represent actual bogie mounting conditions. Four operational load cases were applied.
- 3) Solving: A static structural analysis method was utilized to determine von Mises stress, total deformation, equivalent elastic strain, and safety factor under each load case. The results were examined specifically in the welded joint region to assess structural reliability.

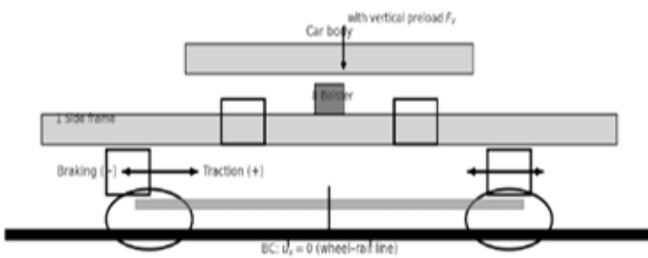


Figure 2: Free Body Diagram Side Frame Bogie

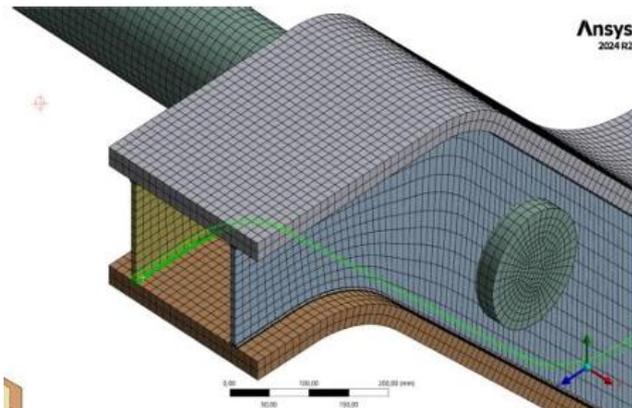


Figure 3: Mesh for Side Frame Bogie

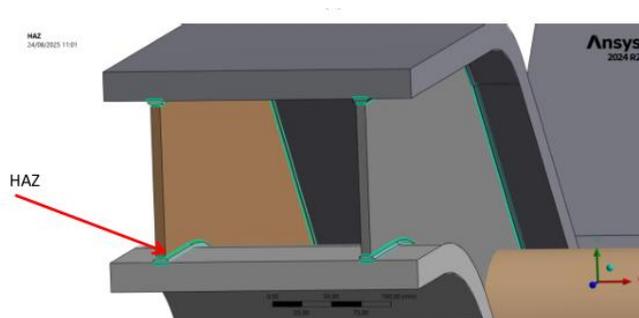


Figure 4: Welding on the bogie side frame

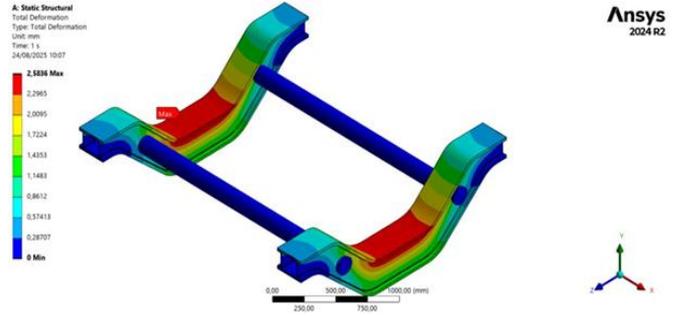


Figure 5: Total Deformation Side Frame bogie Travel Speed 20

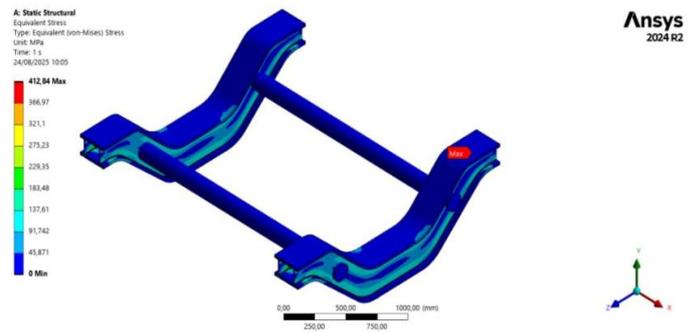


Figure 6: Equivalent Stress Side Frame bogie Travel Speed 20

### 3.2 Load Effect Analysis on Structural Response

Finite element simulations were performed for the side frame using the welding scenario with a travel speed of 20 cm/min, which served as the primary condition for validation. This welding speed was selected because it produced the most stable tensile test results and represented the standard fabrication condition. The simulation revealed the following key structural responses:

- 1) Maximum von Mises stress occurred at the welded joint, primarily at the weld toe region, but remained below the yield strength of SS400, ensuring structural safety.
- 2) Total deformation remained within acceptable design limits for all four load cases, indicating adequate stiffness of the welded structure.
- 3) Safety factor evaluated through the ANSYS static structural tool remained above 1, confirming that the welded joint could withstand operational loads without risk of failure.

These results indicate that the welding parameters corresponding to a travel speed of 20 cm/min result in sufficient joint integrity to carry bogie operational loads.

The structural behavior observed from the primary welding scenario was then used as a reference for comparing weld performance at other travel speeds.

### 3.3 Validation and Design Implication

Validation was conducted by comparing FEM results with tensile testing data for SS400 welded using ER70S-6 filler. The FEM-predicted stress and deformation patterns were consistent with the mechanical behavior observed experimentally:

- 1) Maximum stress values predicted by FEM remained below the allowable stress limits of SS400 for all load cases.
- 2) Safety factors were consistently above 1, indicating that the welded joints are structurally acceptable across all simulated conditions.
- 3) Deformation patterns were proportional to the load magnitude and direction, matching theoretical expectations for welded structural components.

These findings demonstrate that the FEM analysis provides an accurate representation of the welded joint performance. The validated model also offers several design implications. Design implications include:

- 1) The method may be used to determine the most optimal welding parameters for bogie frame fabrication.
- 2) FEM results can support the development of a standardized approach for evaluating welded structural components in railway vehicles.
- 3) The analysis can be extended to assess alternative materials, filler metals, or additional load scenarios without requiring full-scale destructive testing.

Thus, the validated simulation model serves as a reliable tool for ensuring welded joint safety in bogie side frame applications and for supporting the development of optimized welding procedures.

**Table 7: Stress Analysis and Safety Status of Side Frame Bogie**

Welding Speed	Total Deformation	Von Mises Stress (MPa)	Safety Factor	Status
15	2.5843	407.58	0.70538	OK
20	2.5836	412.84	0.70586	OK
25	2.5845	405.82	0.70522	OK

## IV. CONCLUSION

This research concludes that the combination of tensile testing and finite element analysis is effective for evaluating the structural performance of welded joints on the railway bogie side frame. Variations in welding travel speed influence the mechanical properties of SS400 welded with ER70S-6, as observed from changes in tensile strength and fracture behavior.

FEM simulations under four operational load cases showed that stress concentrations occur around the weld toe, but all von Mises stress values remained below the yield strength of SS400. Safety factors for all loading scenarios were above 1, indicating that the welded joints are structurally safe for bogie operation.

The welding travel speed of 20 cm/min demonstrated good alignment between experimental tensile results and FEM predictions, confirming its suitability as the primary validation condition. Overall, the validated FEM approach provides a reliable method for predicting welded joint performance and can be used to support optimized welding procedures and structural assessments in railway applications.

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