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EFFECT OF WELDING CURRENT ON LOW CARBON STEEL CHARACTERISTICS IN SMAW CLADDING PROCESS

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Abstract

The electric current magnitude is a fundamental parameter that directly affects penetration characteristics and weld bead geometry. This study analyzes the effect of current variations on physical and mechanical properties in the cladding process using the Shielded Metal Arc Welding (SMAW) method. The research aims to determine the optimal current settings to improve the surface hardness and structural integrity of cladding layers on low-carbon steel, which is widely used in industrial applications due to its cost-effectiveness and weldability. The urgency of this study lies in the growing demand for durable and wear-resistant surfaces in critical components subjected to high mechanical stress, where improper welding parameters can lead to defects and premature failure. The materials used are low-carbon steel and HV-600 electrodes with a diameter of 3.2 mm. The SMAW method was applied with current variations of 100 A, 120 A, 140 A, and 160 A. The tests carried out were NDT liquid penetrant, macro structure, microstructure, and Vickers hardness. The results indicate a positive correlation between increasing current and hardness values in the weld area, with the highest hardness recorded at 665.803 HVN at 160 A and the lowest at 515.143 HVN at 100 A. Meanwhile, in the Heat Affected Zone (HAZ), a non-linear pattern was observed, with a maximum hardness of 263.237 HVN at 120 A and a minimum of 219.110 HVN at 140 A. Microstructural analysis revealed the formation of ferrite, pearlite, bainite, and martensite phases in the weld area. The findings provide practical benefits by guiding the selection of suitable welding parameters to enhance surface hardness and extend the service life of components, especially in environments demanding high wear resistance.

Keywords: Current variation, welding, cladding, microstructure, hardness

INTRODUCTION

The development of the industry in Indonesia has shown significant progress, with the steel industry being one of the leading sectors. Low carbon steel is widely used in various industrial applications due to its advantages, such as a good balance of performance, economic cost, high ductility, and excellent workability. However, low carbon steel also has drawbacks, including relatively low hardness and wear resistance, which can affect the long-term performance of mechanical components. One of the main issues is wear caused by direct contact between the material and factors such as speed, pressure, and material hardness(Oktaviandy et al., 2023). To address this issue, the weld overlay technique is commonly used as a solution to improve the hardness and wear resistance of low-carbon steel(Xu et al., 2024).

Weld overlay Cladding (WOC) is a welding process in which a coating material is applied to the base metal to enhance mechanical properties such as wear resistance and hardness, improve visual aspects, and restore dimensions (Rajagukguk et al., 2023). This technique can be performed using various methods, one of which is Shielded Metal Arc Welding (SMAW). This method is widely used in the industrial sector due to its ergonomic, economical, and easy-to-apply nature. Previous studies have shown that variations in current during the weld overlay process significantly affect the surface hardness of the cladding and the Heat Affected Zone (HAZ)(Alvarães et al., 2020)(Baghel, 2022).

Based on this background, this study aims to analyze the effect of current variations in the weld overlay process on the macro and microstructure of the base metal, weld area, and HAZ, as well as its impact on Vickers hardness and welding defects. This study uses low-carbon steel as the base material, with the SMAW welding method using HV-600 electrodes with a 3.2 mm diameter. The current variations used are 100 A, 120 A, 140 A, and 160 A. The analysis was conducted through an etching process following ASTM E407-99 standards to observe the microstructure, as well as hardness testing using the Vickers method based on ISO 6507/ASTM E384 standards. Additionally, welding defects were evaluated using the Non-Destructive Testing (NDT) Liquid Penetrant method.

Research on the effect of welding current has also been conducted to understand its impact on the strength of welded joints, given the extensive use of welding in industrial construction. This particular study investigates the influence of welding current on the mechanical properties of welded joints using the Shielded Metal Arc Welding (SMAW) method with current variations of 100 A, 110 A, and 120 A. The base material used is ST60 steel with a thickness of 10 mm, and a single V-groove butt joint with a 70° angle was applied. The results show that the average tensile strength increases with current, recorded at 25.49 Kgf/mm^2 for 100 A, 27.23 Kgf/mm^2 for 110 A, and slightly decreased to 26.49 Kgf/mm^2 at 120 A. The average strain values also increased, from 1.5% at 100 A to 2.16% at 120 A. However, the average modulus of elasticity decreased with higher current, from 16,360 N/mm^2 at 100 A to 11,947 N/mm^2 at 120 A. Based on these findings, the optimal current for balancing strength and ductility is identified as 120 A(Rozi, 2024).

This research is expected to contribute to understanding the effect of current variations on the mechanical properties of low-carbon steel, which can be applied to improve material performance in various industrial applications.

METHODS

The research was conducted using ASTM A36 steel material and HV-600 electrodes through the SMAW welding method with current variations of 100A, 120A, 140A, and 160A. The welding tool used is the Smaw / Mma Dc Igbt Inverter S Series 3 P Welding Machine - Kobewel S 350. The testing process began with Non-Destructive Testing (NDT) using the Liquid Penetrant method to detect visual defects (Hashim et al., 2024) (Azizah et al., 2025). Next, specimen preparation was carried out through a mounting process using resin to facilitate macrostructure, microstructure and hardness testing. The specimens were polished using abrasive paper until the surface was smooth and even, followed by an etching process to observe the microstructure in three main areas: the base metal, weld area, and Heat Affected Zone (HAZ). Visual documentation was performed to record the macrostructure and welding defects.

Microstructure analysis was conducted to identify the phases formed in each area at a single observation point. to find out the microstructure using the Carl Zeiss Axiovert A1 MAT microscope. Finally, Vickers hardness testing was performed in each area with three measurement points to analyze the effect of current variations on hardness values. The hardness test tool used is the Zwick Roell ZHU25CL Universal Hardness Tester Machine with a load of 0.5 kgf held for 10 seconds. Figure 1 shows the cladding process scheme and its testing.

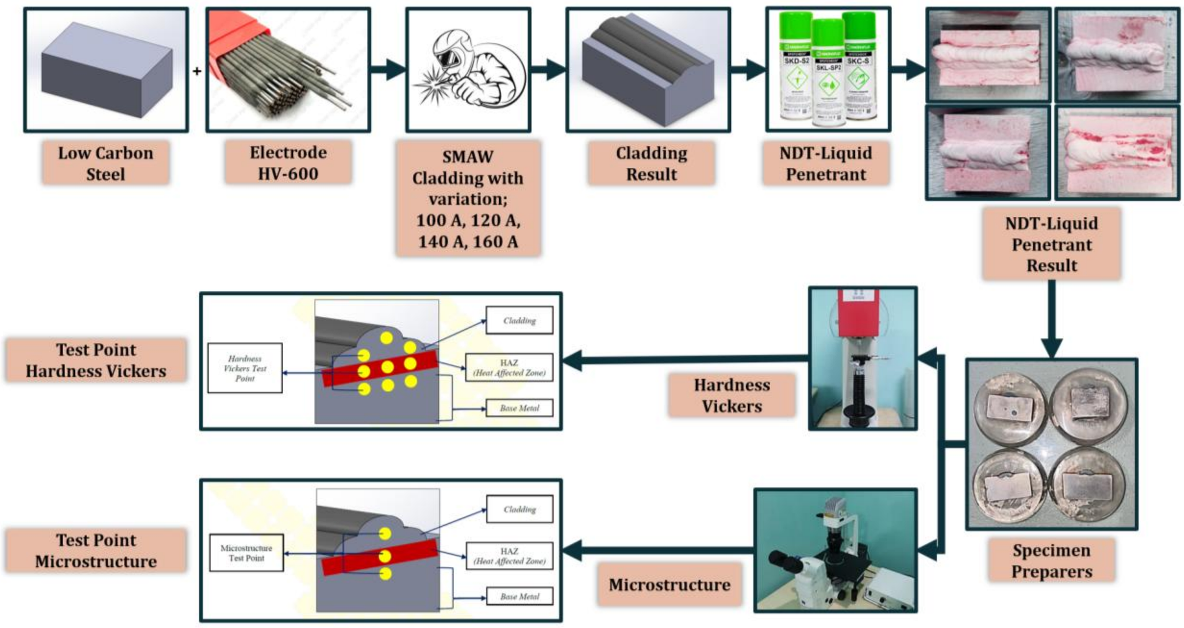

Figure 1. Research Scheme

RESULTS AND DISCUSSION

Liquid Penetrant

Liquid penetrant testing was conducted on ASTM A36 steel specimens after the weld overlay cladding process to visually idenstify welding defects. This method utilizes the capillarity of the penetrant liquid, which seeps into surface discontinuities, followed by the application of a developer to visualize defects (Hashim et al., 2024) (Azizah et al., 2025).

The testing refers to ASME BPVC.VIII and AWS D1.1 standards, which include acceptance criteria for welding defects. These standards define the maximum allowable discontinuities based on the length of the welding seam.

The test results on specimens with varying currents (100 A, 120 A, 140 A, and 160 A) revealed several types of defects: lack of fusion (incomplete fusion between the filler metal and base metal), porosity (pores on the weld surface), cracks, slag inclusion (trapped welding slag), and undercut (erosion of the base metal forming a groove at the weld joint edge)(Anindito et al., 2020)(Paundra et al., 2020).

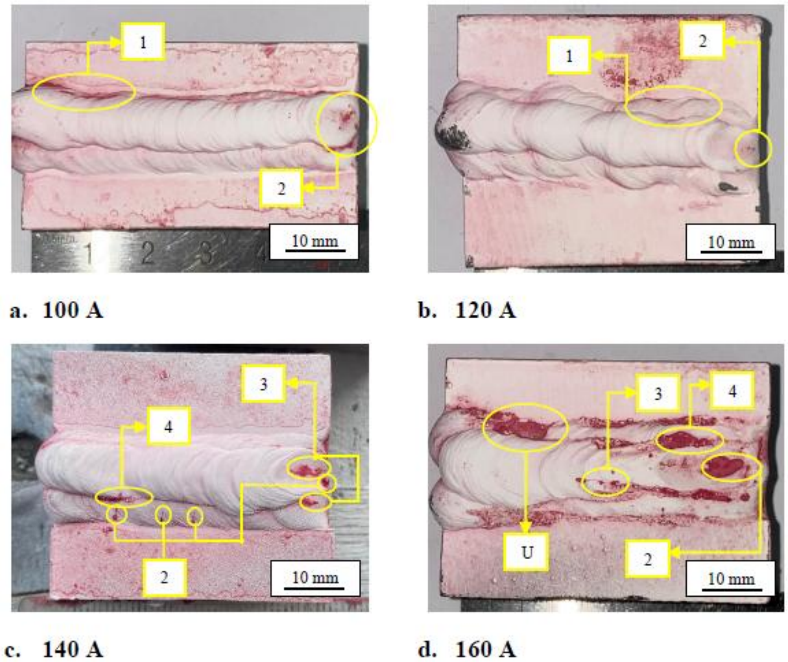

Figure 2. NDT-Liquid Penetrant Test

Macro Structure Testing

Macro structure testing was conducted to analyze the welding results in the weld area, base metal, and Heat Affected Zone (HAZ). Specimen preparation included polishing with abrasive paper and metal polish, followed by an etching process using a mixture of 5% HNO_3 and 95% alcohol (70%) according to ASTM E407-99 standards (Surojo et al., 2021).

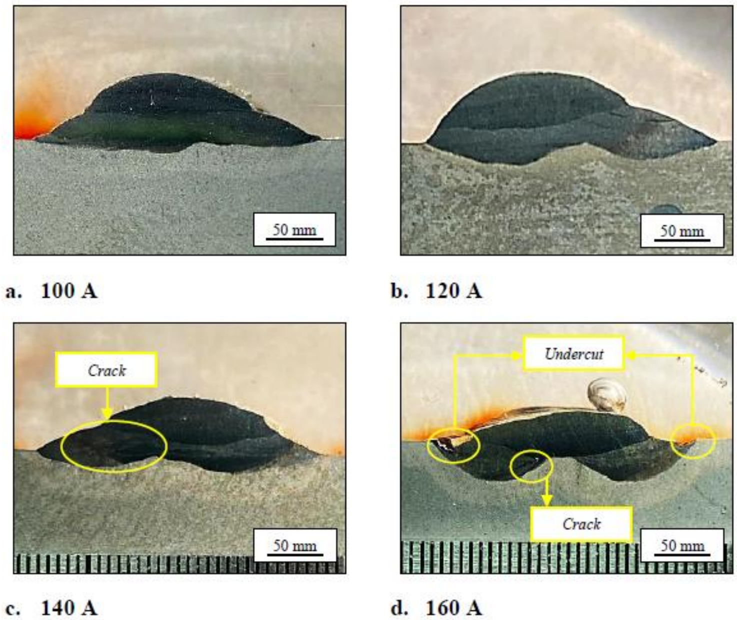

Figure 3. Macro structure

The observations showed that specimens welded at lower currents (100 A and 120 A) exhibited optimal weld joint characteristics without defects in the weld area and HAZ. This indicates a balanced melting and solidification process between the base metal and electrode(Joints et al., 2024). Meanwhile, specimens welded at higher currents (140 A and 160 A) showed defects such as cracks and undercuts in the weld area. This phenomenon occurred due to metallurgical changes in the material, leading to non-uniform phase transformations (Cao et al., 2024).

The research findings indicate that a current range of 100 A to 120 A provides optimal welding results for the material and welding conditions used in this study (Alvarães et al., 2020).

Micro Structure Testing

The base metal used in this study is ASTM A36 steel (low-carbon steel). Micrograph observations at 500x magnification reveal the presence of two phases: ferrite (white/bright areas) and pearlite (gray areas)(Muhyi et al., 2023). Quantitative analysis indicates a dominant ferrite phase, accounting for 68.113% of the total area, while the pearlite phase occupies 31.887%. This characteristic aligns with the composition of ASTM A36 steel, which contains 0.17 wt% carbon, providing a combination of mechanical properties such as good ductility and formability(Matias et al., 2021).

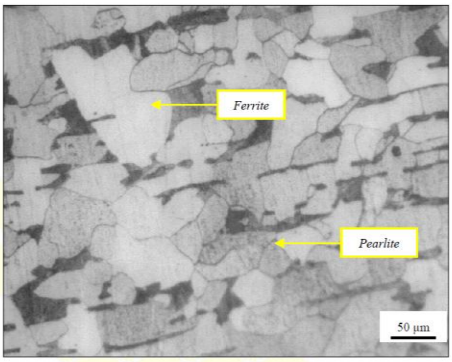

Figure 4. Base Metal

The Heat-Affected Zone (HAZ) is the area influenced by heat and the base metal adjacent to the weld metal, which undergoes a thermal cycle of rapid heating and cooling during the welding process. This causes structural changes due to the high temperatures experienced in this region. The HAZ is the most critical area of the weld joint because, in addition to structural changes, there are also alterations in its mechanical properties. The mechanical strength of the HAZ needs to be determined through tensile testing. In addition to mechanical strength, its structure should also be observed through microstructural examination(Paundra et al., 2020). Microstructural analysis at 500x magnification was conducted to evaluate the effect of varying welding currents (100 A, 120 A, 140 A, and 160 A) on the characteristics of the HAZ

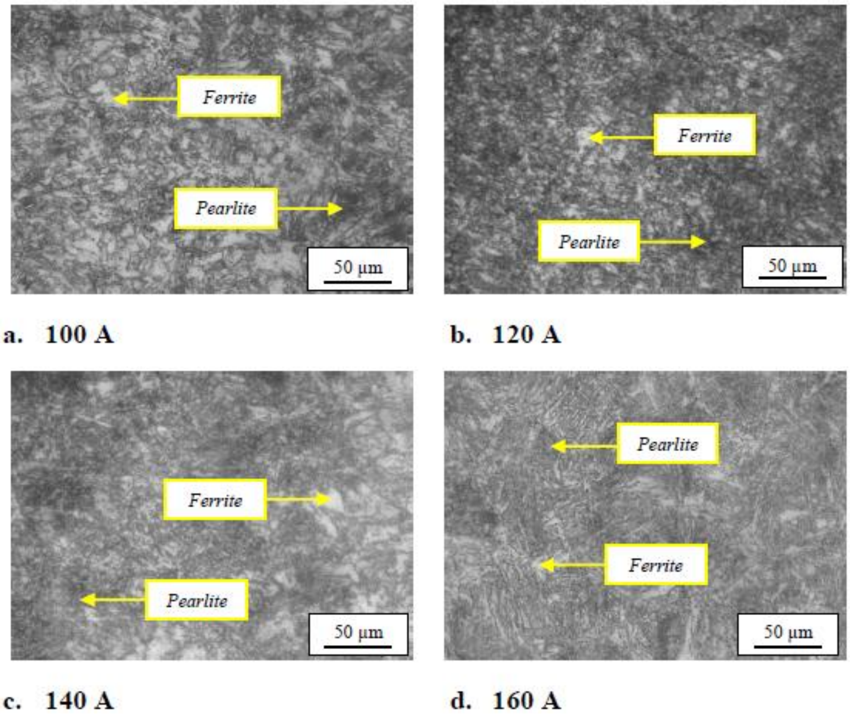

Figure 5. *Heat Affected Zone* (HAZ)

The analysis identified two primary phases: ferrite (bright white) and pearlite (dark gray)(Cao et al., 2024). An increase in welding current directly correlated with changes in phase composition and the width of the HAZ. At 100 A, the ferrite phase constituted 39.678%, while pearlite accounted for 60.322%. As

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the current increased to 160 A, pearlite became the dominant phase (85.917%), with a more defined needle-like cementite structure(Meysami et al., 2024).
This phenomenon is influenced by slow cooling at room temperature, which facilitates extensive pearlite formation [14]. In multi-pass welding applications, maintaining interpass temperature is a crucial factor affecting the final microstructural development (Paundra et al., 2020).

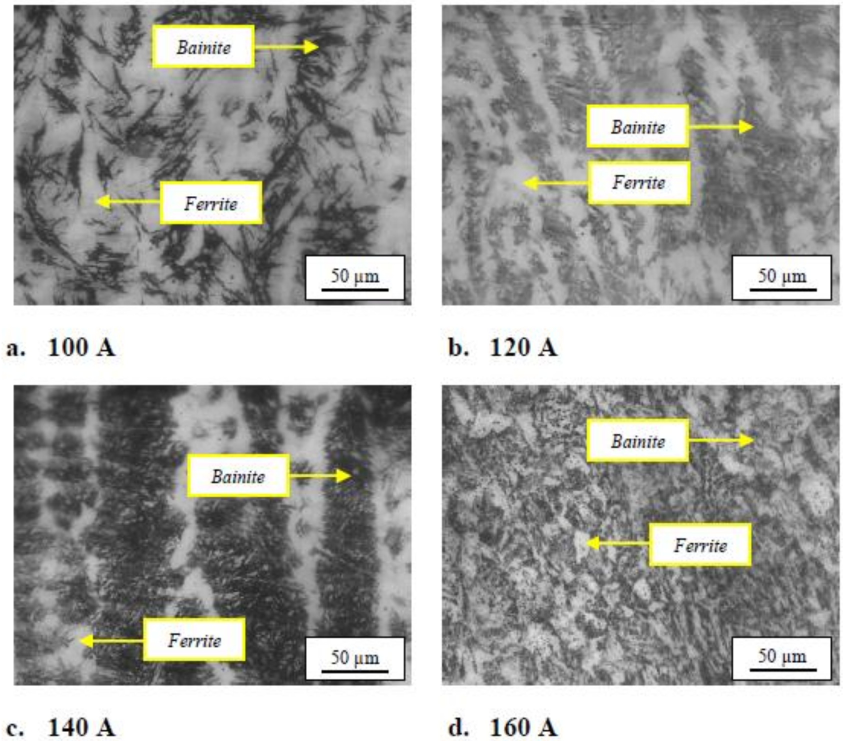

Figure 6. Weld metal Area micro structure

Weld metal is the part of a welded joint that undergoes melting and solidification during the welding process. It consists of filler metal, if used, and a portion of the base metal that has melted and fused together. This region forms the fusion zone, where the weld metal joins the heat-affected zone (HAZ). The properties of weld metal depend on various factors, including the type of filler material, welding technique, heat input, and cooling rate. Proper control of these factors is essential to ensure a strong, defect-free weld with optimal mechanical properties(Xu et al., 2024).

The weld mertal area was analyzed through metallographic observation at 500x magnification to evaluate the effect of varying welding currents on microstructural characteristics. Using an HV-600 electrode with a carbon content of 0.6 wt%, the analysis revealed two dominant phases: bainite and ferrite (Meysami et al., 2024).

Quantitative analysis indicated phase distribution changes with increasing current. At 100 A, ferrite dominated (67.943%) while bainite accounted for 32.057%. As the current increased to 160 A, bainite became the predominant phase (66.559%) with an irregular mixed pattern, while ferrite decreased to 33.441%.

This phase combination is influenced by the chemical composition of the HV-600 electrode and the characteristics of ASTM A36 steel. The presence of strong and tough bainite alongside soft and ductile ferrite contributes to the enhancement of mechanical properties, particularly wear resistance (Meysami et al., 2024)(Pujiyulianto et al., 2022).

Vickers Hardness

Vickers hardness testing is a method used to measure the hardness of a material by using a diamond pyramid shaped indenter with a 136° angle. Vickers hardness testing was conducted using a universal hardness tester with a 5 kgf load and an indentation duration of 10 seconds. The test was performed on three areas: the weld area, the heat affected zone (HAZ), and the base metal.

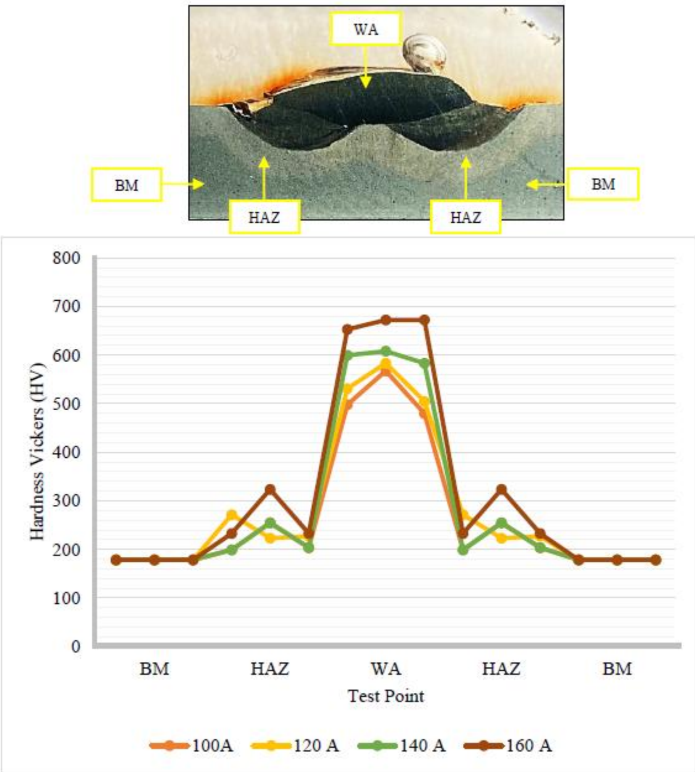

Figure 7. Vickers Hardness Graph

The base metal exhibited an average hardness value of 178.295 HV. In the weld area, hardness values increased with rising welding current, reaching a peak of 665.803 HV at 160 A. This increase is associated with the composition of the HV-600 electrode (0.6 wt% C, 4 wt% Cr, 1 wt% Mn) and the presence of the bainite phase.

In the HAZ, hardness values also showed an increasing trend with rising current: 219.11 HV (100 A), 240.613 HV (120 A), 252.043 HV (140 A), and 263.237 HV (160 A). This phenomenon is influenced by the formation of pearlite and ferrite phases due to slow cooling, as well as variations in grain growth rate affected by welding current (Alvarães et al., 2020).

CONCLUSION

This study concludes that welding current significantly affects the quality and mechanical properties of cladding using the SMAW method. Liquid penetrant tests showed that higher currents (140 A and 160 A) caused more visual defects due to increased internal stress and uneven phase transformations. Macrostructure analysis indicated that lower currents (100 A and 120 A) produced more uniform and defect-free welds. Microstructural observations revealed ferrite dominance in the base metal, while bainite and cementite formed at higher currents, particularly at 160 A, enhancing hardness and strength. Hardness tests showed the highest value in the weld area at 665.803 HV (160 A), while the base metal had the lowest at 178.295 HV. These results confirm that selecting an optimal current is essential for achieving desirable microstructural and mechanical characteristics in welded components.

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