

## Influence of Spray Angle in Vapor Blasting on Thickness Reduction, Surface Roughness, and Hardness of Aluminum Crankcase Material

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### ABSTRACT

This study investigates the effect of vapor blasting spray angle on the thickness, surface roughness, and hardness of aluminum crankcase material. Twelve specimens measuring  $30 \times 30 \times 3$  mm were prepared, consisting of untreated samples and samples treated at spray angles of  $60^\circ$ ,  $70^\circ$ , and  $80^\circ$ . Vapor blasting was performed at 40 psi using a 5 mm nozzle, glass bead media of 90–150  $\mu\text{m}$ , a spray distance of 5 cm, and a treatment time of 5 min. Increasing spray angle reduced thickness from 3.00 to 2.95, 2.93, and 2.92 mm and increased surface roughness from 0.122 to 0.639, 1.075, and 1.200  $\mu\text{m}$ , respectively. Surface hardness changed only slightly from 65.7 to 66.41, 66.84, and 66.51 HV and was not significantly affected by spray angle. In contrast, cross-sectional hardness showed a statistically significant but practically small increase. These results demonstrate that spray angle is a key parameter in vapor blasting, primarily governing material removal and surface texturing while exerting only a limited effect on hardness under the present operating conditions

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## INTRODUCTION

One of the aluminum-based components commonly found in motorcycle engines is the crankcase, which functions as the housing for the crankshaft and its supporting bearings in an internal combustion engine. In service, the crankcase is exposed to oil deposits, dirt, combustion residues, and fine metallic particles that can accumulate on its surface and within its cavities (Bekibele et al., 2022; Dyson et al., 2024; Solangi et al., 2025). Such contamination can interfere with inspection, maintenance, and restoration procedures, thereby creating the need for an effective cleaning method that can remove contaminants without excessively degrading the substrate surface.

Abrasive blasting is widely employed in industrial practice as a surface-cleaning and surface-preparation method, especially for contaminant removal, surface activation, and pre-coating treatment (Gadge et al., 2022; Ruhm et al., 2025). Process performance is governed by several operating parameters, including inlet pressure, abrasive flow rate, particle size, stand-off distance, and blasting angle, all of which influence surface roughness, cleanliness, and productivity (Sunardi et al., 2017). In practice, blasting angle is an important yet often empirically selected variable, despite its direct effect on the interaction between abrasive particles and the target surface (Nguyen et al., 2024).

Compared with conventional dry blasting, wet abrasive blasting or vapor blasting offers several advantages, such as reduced dust generation and a more controlled interaction between abrasive particles and the treated surface (Zulkarnain et al., 2021). Wet blasting has also been reported as an effective process for aluminum treatment and deburring, indicating its suitability for components that require cleaning with limited surface damage (Yang et al., 2014).

Previous studies have shown that blasting parameters can significantly alter surface integrity. Increasing abrasive severity, such as grit size or pressure, generally increases surface roughness and modifies surface morphology (Tshimanga et al., 2021). Likewise, recent studies on aluminum substrates have demonstrated that blast-cleaning methods can substantially affect surface morphology, while the condition of the treated surface depends strongly on the selected process variables (Dai et al., 2024). However, studies specifically addressing the effect of spray angle in vapor blasting of aluminum crankcase material remain limited, particularly in relation to the combined responses of material removal, surface roughness, and hardness.

Therefore, this study investigates the effect of vapor blasting spray angle on the thickness reduction, surface roughness, and hardness of aluminum crankcase material. Spray angles of 60°, 70°, and 80° were selected to evaluate how changes in particle impact orientation influence dimensional reduction and surface characteristics. The findings are expected to provide practical guidance for parameter selection in cleaning, maintenance, and surface treatment of aluminum crankcase components.

## THEORETICAL REVIEW

Aluminum alloys are widely adopted in transportation and machinery because they combine low weight with good corrosion resistance and acceptable mechanical performance (Krall et al., 2024; Li et al., 2023). For crankcase applications, these properties are essential because the component must maintain structural function while being exposed to service contaminants and environmental effects. As a result, cleaning and restoration methods for crankcases must be able to remove deposits effectively without causing excessive dimensional loss or degradation of the surface layer.

Vapor blasting is a wet abrasive treatment process in which abrasive particles are delivered by a mixture of water and compressed air onto the target surface (Gadge et al., 2022). Compared with dry blasting, the presence of water reduces airborne dust and moderates the particle-surface interaction, which can help produce a cleaner and more controlled finishing effect (Huang et al., 2025). The final surface condition, however, depends strongly on process variables such as abrasive characteristics, pressure, stand-off distance, and impact angle (Dai et al., 2024; Gadge et al., 2022; Park et al., 2025; Sunardi et al., 2017). These variables determine particle momentum and impact energy, which in turn influence crater formation, micro-cutting, local deformation, and material removal.

Spray angle plays a central role in blasting behavior because it governs the relative balance between tangential and normal impact components. Lower impact angles tend to promote sliding and scratching, whereas higher angles increase direct impingement and indentation effects (Kumar et al., 2025). Consequently, increasing spray angle may intensify material removal and increase surface roughness due to stronger peak-valley formation. Previous work has also shown that blasting parameters can influence near-surface hardness, although the magnitude of hardness change depends on process severity and substrate response

Based on this theoretical framework, vapor blasting spray angle is expected to have a stronger influence on material removal and surface roughness than on hardness. For aluminum crankcase material, evaluating these responses is important to determine a blasting condition that achieves effective cleaning while preserving dimensional and mechanical integrity.

## METHODOLOGY

### *Materials and Specimen Preparation*

This study employed an experimental method to investigate the effect of spray angle in the vapor blasting process on the thickness, surface roughness, and hardness of aluminum crankcase material. The test material was obtained from a motorcycle crankcase made of aluminum. The crankcase was sectioned into 12 specimens, each measuring  $30 \times 30 \times 3$  mm. The specimens were divided into four groups: three untreated specimens as the control group, and three treatment groups blasted at spray angles of  $60^\circ$ ,  $70^\circ$ , and  $80^\circ$ , respectively. The detailed dimensions of the specimens are shown in Figure 1.

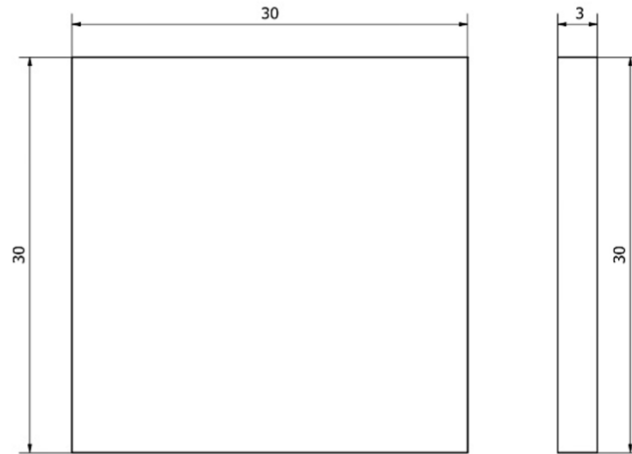


Figure 1. Test Specimen Dimensions

### *Vapor Blasting Procedure*

The vapor blasting process was carried out using a machine with dimensions of 75 × 60 × 150 cm. The operating conditions were maintained constant for all treated specimens, including an air pressure of 40 psi, a nozzle diameter of 5 mm, glass bead abrasive media with a particle size range of 90–150 μm, a spray distance of 5 cm, and a blasting duration of 5 min. In this study, spray angle was the only intentionally varied parameter, while the other processing variables were controlled to ensure that the observed changes in thickness, roughness, and hardness could be attributed primarily to the variation in impact angle. A diagram of the vapor blasting setup used in this study is shown in Figure 2.

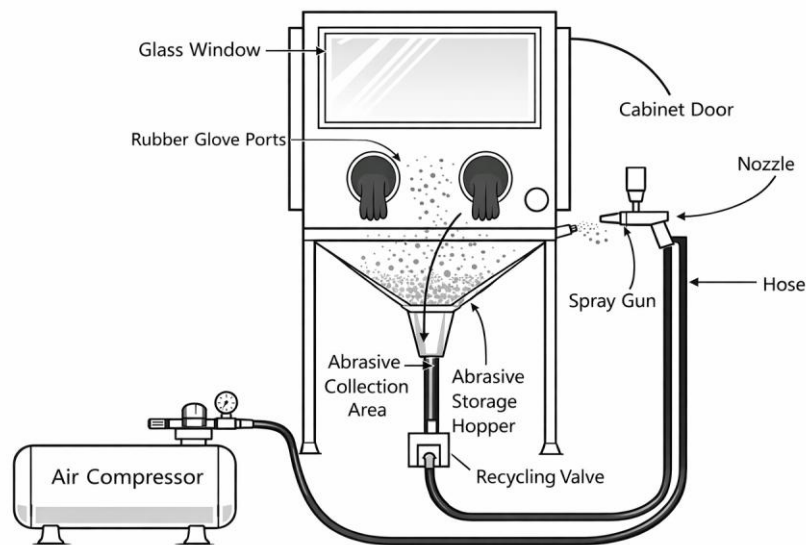


Figure 2. Vapor blasting setup diagram

**Thickness Measurement**

Thickness reduction was measured using a vernier caliper with an accuracy of 0.02 mm. For each specimen, measurements were taken at three points on the specimen surface, and the average value was used as the representative thickness. This measurement was intended to evaluate the extent of material removal caused by abrasive particle impact during vapor blasting. The layout of the measurement points and the spacing for data acquisition on the specimen are shown in Figure 3.

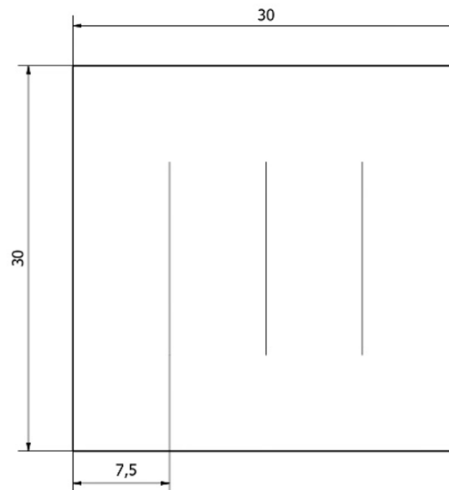


Figure 3. Thickness Measurement test point with Vernier Caliper on specimen

**Surface Roughness Measurement**

Surface roughness was measured using a surface roughness tester on the specimen surface (Figure 4). The test locations were selected according to ISO 4288 by considering the minimum spacing between measurement points and the minimum distance from the specimen edge. A total of seven measurement points were used for each condition, with a sampling length of 0.8 mm. The arithmetic average roughness,  $R_a$ , was used as the roughness parameter, as expressed in Eq. (1):

$$R_a = \frac{1}{l} \int |y(x)| dx \dots \dots \dots (1)$$

where  $R_a$  is the average surface roughness,  $l$  is the measured profile length, and  $y(x)$  is the profile height deviation at position  $x$ .

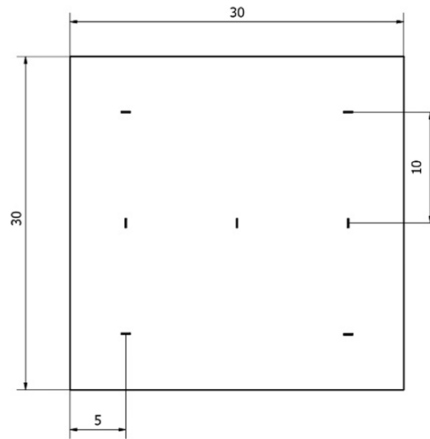


Figure 4. Roughness measurement test points on the specimen surface

**Hardness Testing**

Hardness was evaluated using the micro-Vickers method with a diamond pyramid indenter having an apex angle of 136° (Figure 5). A load of 500 gf (0.5 kgf) was applied for 15 s. After indentation, the impression diagonals were observed using an optical microscope, and the Vickers hardness value was calculated using Eq. (2):

$$HV = 1.854 \frac{P}{d^2} \dots\dots\dots(2)$$

where *HV* is the Vickers hardness, *P* is the applied load (kgf), and *d* is the average indentation diagonal length (µm).

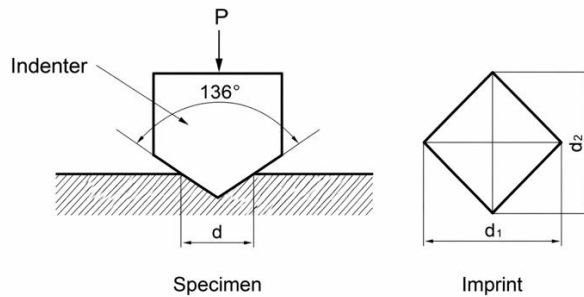


Figure 5. Schematic illustration of the Micro-Vickers hardness test and indentation geometry

Measurements were taken at five points on the specimen surface and ten points on the specimen cross-section (Figure 6) The spacing between indentation points followed ISO 6507-1.

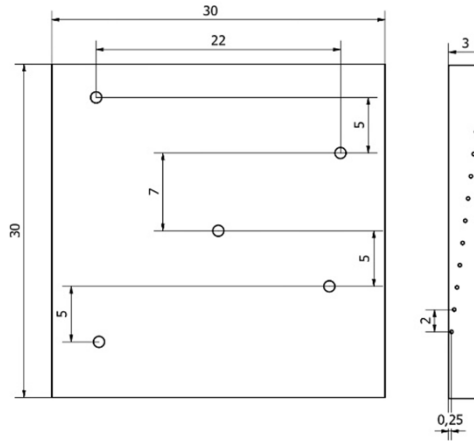


Figure 6. Vickers Micro test points on the specimen cross section

### Statistical Analysis

The experimental data were analyzed descriptively and statistically. Mean values were calculated for each response variable, namely thickness, surface roughness, and hardness. One-way analysis of variance (ANOVA) was then performed to determine whether the spray angle significantly affected the measured responses. The significance level was set at 0.05.

## RESEARCH RESULTS

### Thickness Reduction

The average thickness of the untreated specimen was 3.00 mm. After vapor blasting, the average thickness decreased to 2.95 mm at a spray angle of 60°, 2.93 mm at 70°, and 2.92 mm at 80° (Figure 7). These values indicate that the increase in spray angle was followed by a progressive reduction in specimen thickness. The corresponding thickness reduction values were 0.05 mm, 0.07 mm, and 0.08 mm, respectively. Statistical analysis using one-way ANOVA showed that spray angle had a significant effect on thickness reduction, with an F-value of 22.067 and  $p < 0.001$  (Table 1).

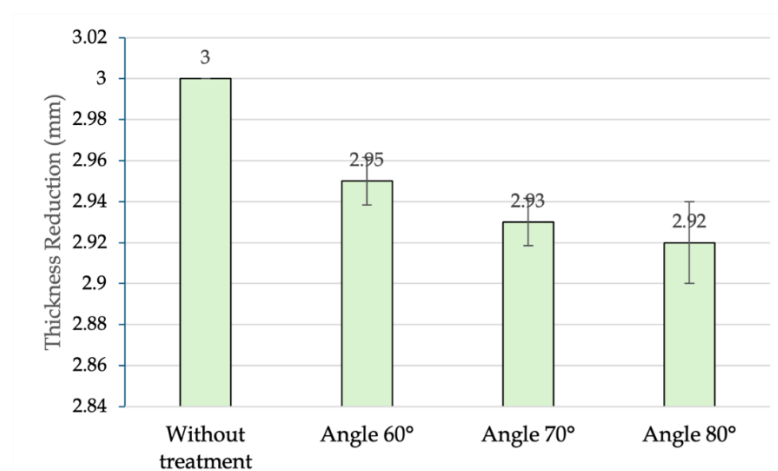


Figure 7. Comparison of the average thickness of specimens before and after vapor blasting at different spray angles

Table 1. One-way ANOVA results for the effect of vapor blasting spray angle on specimen thickness

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.011	3	0.004	22.067	<0.01
Within Groups	0.001	8	0.000		
Total	0.012	11			

### Surface Roughness

The untreated specimen exhibited an average surface roughness of 0.122  $\mu\text{m}$ . After treatment, the average roughness increased to 0.639  $\mu\text{m}$  at 60°, 1.075  $\mu\text{m}$  at 70°, and 1.200  $\mu\text{m}$  at 80°. This result shows a consistent increase in surface roughness with increasing spray angle. The ANOVA result confirmed that the effect of spray angle on surface roughness was statistically significant, with an F-value of 227.179 and  $p < 0.001$  (Table 2).

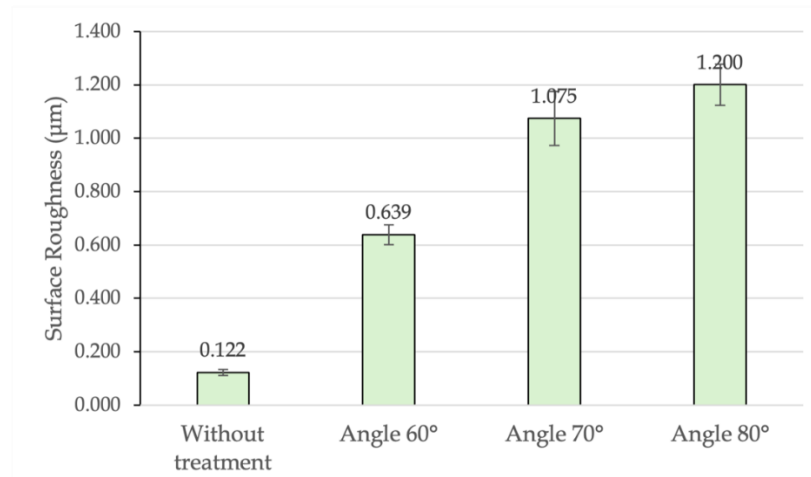


Figure 8. Average surface roughness of specimens before and after vapor blasting at different spray angles

Table 2. One-way ANOVA results for the effect of vapor blasting spray angle on surface roughness

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.155	3	1.718	227.179	<0.001
Within Groups	0.182	24	0.008		
Total	5.337	17			

### Surface Hardness

The average surface hardness of the untreated specimen was 65.7 HV. After vapor blasting, the average hardness values were 66.41 HV at 60°, 66.84 HV at 70°, and 66.51 HV at 80°. Although slight changes were observed among the treated groups, the differences were small. One-way ANOVA showed that spray angle did not significantly affect surface hardness, with an F-value of 1.476 and  $p = 0.259$  (Table 3).

Table 3. One-way ANOVA results for the effect of vapor blasting spray angle on surface hardness

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3.414	3	1.138	1.476	0.259
Within Groups	12.334	16	0.771		
Total	15.748	19			

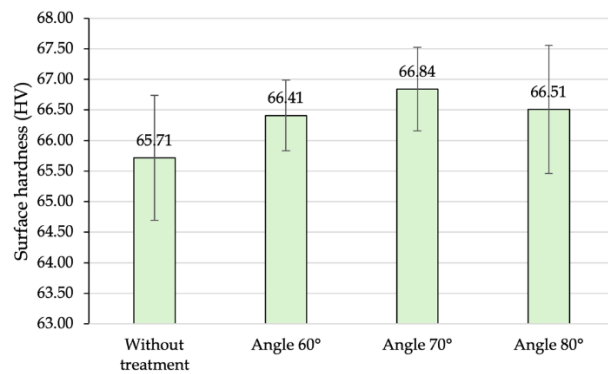


Figure 9. Average surface hardness of specimens before and after vapor blasting at different spray angles

### Cross-Sectional Hardness

The average cross-sectional hardness of the untreated specimen was 65.48 HV. After vapor blasting, the average values became 65.53 HV at 60°, 65.87 HV at 70°, and 66.46 HV at 80°. The graph also shows that the hardness distribution across the specimen cross-section, from the surface toward the interior, generally tended to decrease at all spray-angle variations (Figure 10). Compared with the untreated condition, the increase was relatively small. However, the ANOVA result showed a statistically significant difference among groups, with  $F = 4.265$  and  $p = 0.011$  (Table 4).

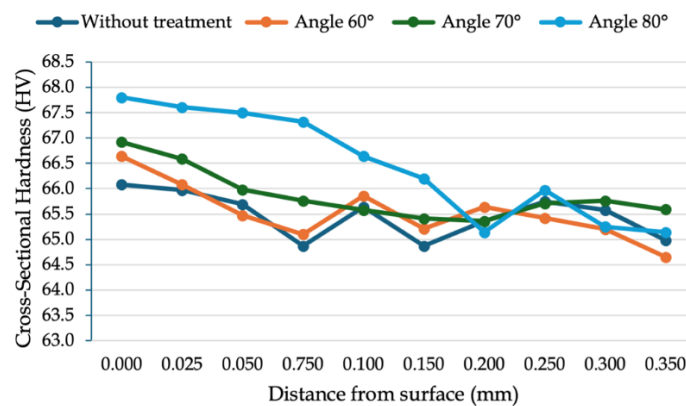


Figure 10. Relationship between the cross-sectional hardness distribution of the specimen and spray-angle variation during the vapor blasting process

Table 4. One-way ANOVA results for the effect of vapor blasting spray angle on Cross-Sectional Hardness

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6.094	3	2.031	4.265	0.011
Within Groups	17.148	36	0.476		
Total	23.242	39			

## DISCUSSION

The results demonstrate that increasing spray angle intensified the interaction between abrasive particles and the aluminum crankcase surface. This behavior was clearly reflected in the reduction of specimen thickness. A higher spray angle increased the normal impact component, which promoted stronger direct impingement and therefore greater material removal. This finding is consistent with blasting theory, which states that impact angle strongly affects the erosion mechanism and surface response (Bell & McCartney, 2020; Kumar et al., 2025).

A similar pattern was observed in surface roughness. The progressive increase in roughness from 0.122  $\mu\text{m}$  in the untreated condition to 1.200  $\mu\text{m}$  at 80° indicates that higher spray angles produced a more pronounced surface texturing effect. This can be attributed to stronger indentation and crater formation caused by more perpendicular abrasive impacts. Previous studies have likewise reported that blasting parameters, especially impact angle and pressure, can substantially modify roughness and surface morphology. Among all measured variables, roughness showed the strongest response to spray angle, indicating that surface topography is highly sensitive to impact orientation (Dai et al., 2024; Park et al., 2025).

In contrast, surface hardness changed only slightly and was not significantly influenced by spray angle. This suggests that, under the present conditions, vapor blasting mainly altered the outer geometry of the surface rather than producing substantial work hardening or microstructural transformation in the near-surface region. The relatively mild effect may be associated with the use of glass bead media and moderate blasting conditions. This trend is consistent with prior studies showing that blasting can affect hardness, but that the extent of change depends strongly on process severity and substrate characteristics (Sunardi et al., 2017).

For cross-sectional hardness, the statistical analysis showed significance, but the increase in average values remained practically small. This indicates that vapor blasting may have induced a limited subsurface effect, although its magnitude was much smaller than the changes observed in thickness and surface roughness. Overall, the present findings indicate that spray angle primarily controls material removal and surface texturing, while its influence on hardness remains limited under the selected operating conditions.

## **CONCLUSIONS AND RECOMMENDATIONS**

This study demonstrated that spray angle is a critical parameter in the vapor blasting of aluminum crankcase material. Increasing the spray angle from 60° to 80° increased thickness reduction and surface roughness, indicating stronger abrasive impact and greater material removal at higher impact angles. Surface hardness exhibited only minor variation and was not significantly affected by spray angle, whereas cross-sectional hardness showed a statistically significant but practically limited increase.

These results indicate that spray angle can be effectively used to control cleaning intensity and surface texture in vapor blasting applications. For practical use, lower spray angles may be preferred when dimensional preservation is critical, while higher spray angles may be selected when stronger cleaning action and more pronounced surface texturing are required. Accordingly, process parameter selection should be adjusted to the functional requirements of the treated aluminum component.

## **FURTHER STUDY**

Further studies are recommended to examine the combined effects of spray angle with other process parameters, such as blasting pressure, stand-off distance, abrasive size, and treatment duration. Surface morphology analysis using microscopy would also provide deeper insight into crater formation and surface damage mechanisms after blasting. In addition, future work should investigate the influence of vapor blasting on other functional properties, such as residual stress, wear resistance, corrosion behavior, and fatigue performance, in order to establish a more comprehensive understanding of the process for aluminum automotive components

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