



Effect of the addition of backing support plates on the shear strength of aluminium and steel adhesively bonded joints

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ABSTRACT

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The use of adhesive joints has been increasing in joining metallic and non-metallic materials due to advantages such as homogeneous stress distribution and a smooth surface appearance. This study aims to analyze the effect of support plates on the shear strength of aluminium and steel adhesively bonded joints. The position of the support plates was studied within the overlap area. Experimental testing was carried out using single lap joint specimens per ASTM D1002. Finite element modelling was also carried out using Abaqus software to analyze the stress distribution in the adhesive layer. The experiment results showed that the addition of the support plates did not increase the shear strength of the joint, but instead tended to decrease it. The strength of aluminium joints with support plates at a distance of 3.125 mm from the end of the lap of the joint decreased by 62%, while the strength of steel joints decreased by about 38%. Finite element modelling results show that von Mises stress at the end of the lap joint decreased with the addition of support plates.

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1. INTRODUCTION

With the advancement of today's technology, adhesively bonded joints are increasingly used to connect metal and non-metallic. This method is more effective than welded joints, rivet joints, and bolt joints, and these joints can be applied to metal and non-metallic structures because they have a more homogeneous stress distribution, are lightweight, and have a smooth surface appearance (Sugiman, 2022). Among the many types of adhesives, epoxy adhesives are most widely used as structural adhesives because *epoxy* can bond both various metal and non-metal surfaces with or without treatment. Epoxy adhesives can operate effectively in harsh environments while preserving their exceptional strength and durability. They exhibit resistance to chemicals

and heat, provide electrical insulation, facilitate thermal conductivity, and can cure even under challenging conditions such as cold, moisture, and wet surroundings (Schlecht, 2023).

Joint design has an important role in obtaining good joint strength. Although the stress distribution is more homogeneous than pin/rivet or bolt joints, the stress concentration remains at the end of the joint where the load transfer from the adherend to the adhesive and from the adhesive to the adherend occurs. The presence of this stress concentration can initiate failure, which then decreases the strength of the connection. Various methods have been carried out to lower the stress concentration at the end of the joint, such as by using a thicker adhesive thickness, adding fillet at the end of the joint, and thickening the adhesive at the end of the joint. The thicker adhesive has more uniform stress distribution in the adhesive layer, but in general, it reduces the joint strength because there are more possible defects in the adhesive (Fernández-Cañadas et al., 2019). The presence of fillets reduces stress concentration due to smoother load transfer (Zheng et al., 2020; Ramaswamy et al., 2022). The internal taper design with an adhesive fillet achieved the most significant reduction in both peel and shear stresses, decreasing them by 88.58% and 39%, respectively, compared to the unmodified base geometry (Ejaz et al., 2022).

The geometry of the adherend can also affect the stress distribution and strength of the joint. The thicker the adherend, the lower the stress concentration at the end of the joint because the bending due to the non-linear load decreased, as explained by Shang et al. (2019). Tapering the adherend at the end of the joint also reduced stress concentration by up to 3 times because the end of the joint became more flexible, according to Golewski and Sadowski (2017). Kanani et al. (2020) reported that notches on the adherend at the end of the joint and inside the joint decreased the stress concentration and increased the joint strength significantly. Moreover, a thicker adherend led to greater flexural rigidity, enhancing the joint's capacity to withstand bending moments. As a result, the fatigue strength limit of the joint was significantly improved (Sahin and Akpınar, 2021).

To reduce stress concentrations, *patches* can be used e.g. for butt joints and for the repair of composites and cracked materials. The use of patches is very effective in reducing the stress concentration at the end of the joint, because it reduces the bending stress due to the rotation of the joint in a single overlapping joint. For single lap joints, a support plate can be provided to reduce rotation due to joint bending. Demir et al. (2020) investigated the addition of supports to single lap joints with an overlap length of 25 mm and a support length of 35 mm, with variations in the support distance from the end of the joint of 0-20 mm. The results showed that the supports glued at a distance of 10 mm from the end of the joint gave the best results. Calik (2025) studied numerically the effect of support patch on single lap joint strength and found similar results as Demir et al. (2020) reported. Those studies used an overlap length of 25 mm, the strength of which tends to decrease compared to the shorter overlap length. This was because the peel (normal) stress, which was responsible for failure initiation, was high for the longer overlap.

Previous research, such as that conducted by Demir et al. (2020) and Calik (2025), generally focused on longer overlap lengths. The research has not specifically examined the performance of a joint with very short overlap lengths, such as the standard overlap of 12.5 mm, which has higher stress concentration than the longer overlap length, and is still not widely reported. Therefore, this study aims to determine the effect of the distance of the support plate from the end of the lap on the shear strength of aluminium joints. The finite element method is used to investigate the stress distribution of each variation.

2. RESEARCH METHODS

2.1 Material

The materials used were 6061 aluminium strip and low carbon steel as an adherend, and Araldite epoxy as an adhesive. Araldite adhesive has two components: epoxy resin and hardener. The specifications of Araldite adhesives used are shown in Table 1.

Table 1. Specification of Araldite epoxy adhesive

Density	1.1 – 1.4 g/cm ³
Resin to hardener weight ratio	1:0.8
Gel time (18-24°C)	5 minutes
Curing initiation time (at room temperature)	± 2 hours
Full curing time (at room temperature)	24 hours

2.2 Manufacture of joint specimens

The 6061 aluminium strip as an adherend (joined material) has dimensions of 100 mm in length, 20 mm in width, and 2 mm in thickness. The aluminium strip 6061 as a support plate was cut with a length of 25 mm, a width of 20 mm and a thickness of 2 mm. The aluminium surfaces of both the adherend and the support plate

were sandblasted and then cleaned using acetone and wiped using a tissue to keep the surface dry. Araldite adhesive was prepared by mixing resin and hardener with a weight ratio of 1:0.8, then manually stirred for 5 minutes until well mixed. After the adhesive was prepared, it was then applied to the surface of the aluminium surfaces evenly. The two surfaces of the adherend were then put together and clamped with paper clips on both sides.

After the bonding was complete, the specimen was then put in the oven for curing at 70°C for 2 hours and left for 24 hours in the oven with the oven switched off. The details of the single lap joint (SLJ) specimen can be seen in Figure 1. The same bonding process was also carried out on steel adherends. The support plate was bonded at the SLJ, with the variation in the position of the support plate (L) being 3.125, 6.25 and 12.5 mm from the end of the joint (see Figure 1). However, the steel joint with the backing support plate was only done in the 3.125 mm position. The material of the support plate was the same as the adherend material: aluminium for aluminium joints and steel for steel joints.

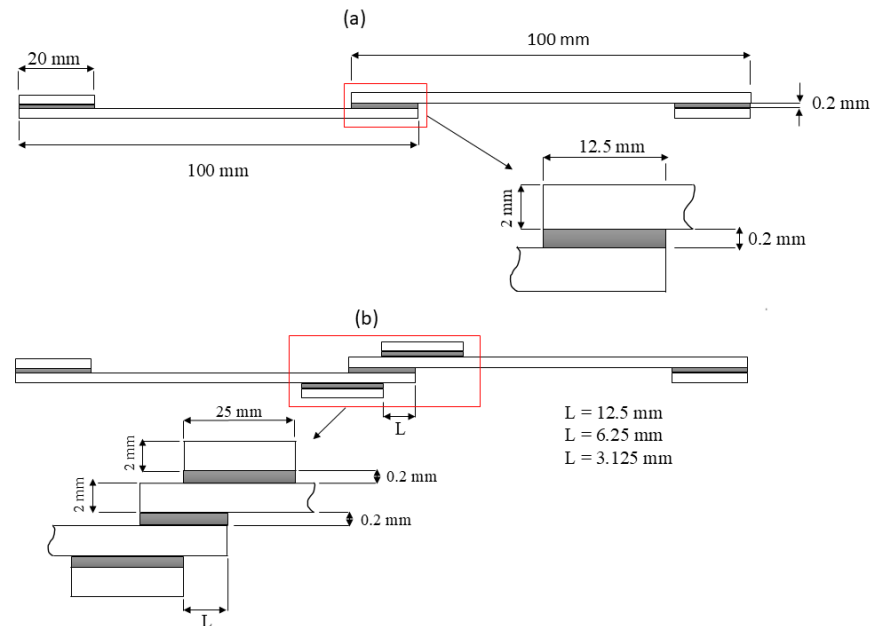


Figure 1. Single lap joint adhesive joint specimens (a) without and (b) with support plates.

2.3 Joint testing

Specimen testing was carried out using a Tensilon testing machine with a load cell capacity of 10 kN. The displacement rate for the testing was 2 mm/min. The number of specimens tested was 4. Once the specimen was broken, the failure surface was visually examined to determine its failure mode.

2.4 Finite element modelling (FEM)

The FEM was used to analyze the stress distribution of von Mises, normal stress and shear stress on the adhesive layer without and with backing plates. The stress distribution can indicate the influence of the support plate on the strength of the connection. The FEM was carried out using Abaqus software. The FEM required data in the form of elastic modulus and Poisson ratio of adherend, adhesive and support plates. The FEM assumed that the adhesives, adherends and backing plates was linear elastic. FEM used a 2-dimensional (2D) model. The properties of adhesives, adherend and backing plates are given in Table 2. In this FEM, the bonding between substrate dan adhesives was assumed to be perfect, and the adhesive was free of flaws. The FEM also did not consider the plasticity of substrate and damage progression of the adhesive, so the analysis of stresses was mainly under elastic behavior.

The boundary conditions and loading on the single lap joint model are depicted in Figure 2. To obtain the stress distribution in the adhesive layer, the joint was subjected to a load of 1000 N. The mesh for the SLJ model is depicted in Figure 3. The global size of the mesh is 0.25.

Table 2. Material properties of adherend and adhesive

Material	Elastic modulus, E (MPa)	Rasio Poisson (ν)
Aluminium (Al)	70000	0.33
Adhesive	1800	0.35
Low carbon steel	200000	0.3

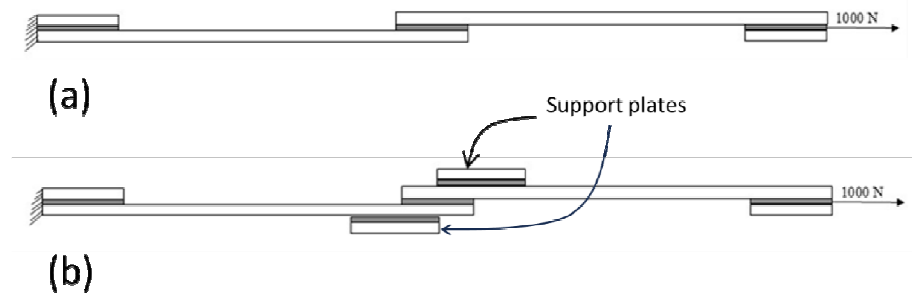


Figure 2. Sketch of boundary conditions of SLJ. The left end was fixed, while the right side was loaded with a load of 1000 N. (a) Showing a SLJ without support plate and (b) with support plates at $L = 6.25$ mm.

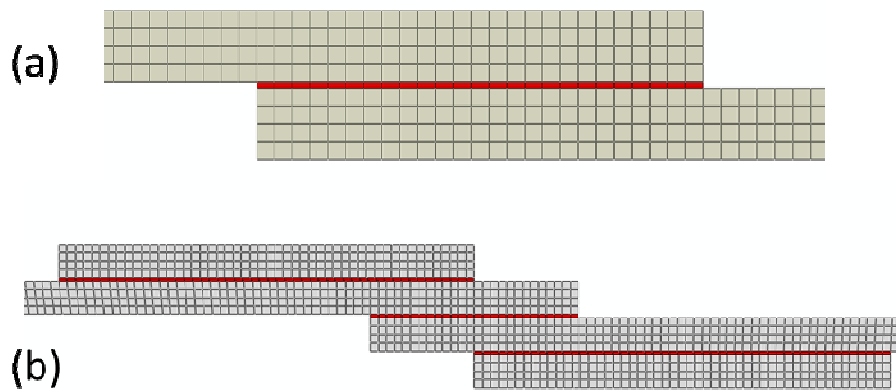


Figure 3. Meshing on single lap joint joints (a) without support plates, (b) with support plates located at 6.25 mm from the end of lap.

3. RESULTS AND DISCUSSION

3.1 Shear strength

The shear strengths for joints without and with aluminium backing support plates at a distance from the end of lap (L) = 12.5 mm, 6.25 mm, and 3.125 mm, and steel joints without and with steel support plates at $L = 3.125$ mm are shown in Figure 4.

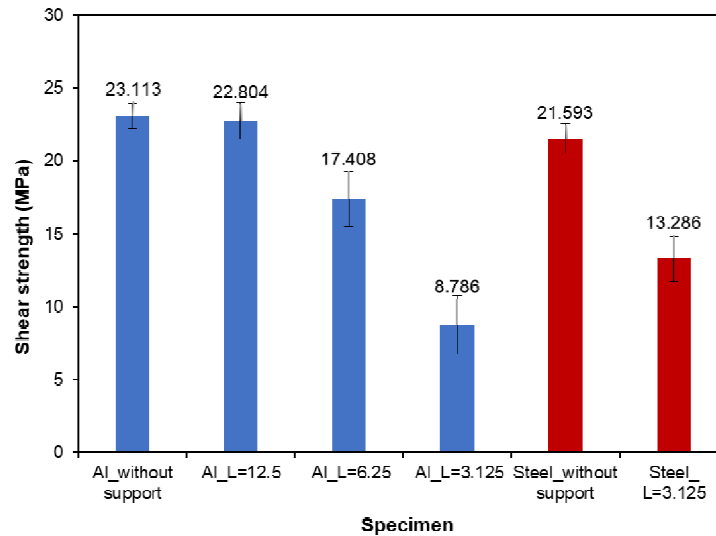


Figure 4. The shear strength of aluminium and steel adhesively bonded joints without and with support plates located at different locations from the end of lap (L).

Figure 4 shows the shear strength of the joints without and with the support plate at different locations. Based on Figure 4, the application of the support plates to the joint significantly impacts the average shear strength value of the aluminium and steel joints. There is a consistent decrease in the average shear strength with an increase in the distance of the support plates from the end of the joint. In aluminium joints without support plates, the average shear strength is 23.11 MPa. After adding aluminium support plates positioned at a distance from the end of lap (L) of 12.5, 6.25 and 3.125 mm, the average shear strength decreased to 22.80 MPa, 17.41 MPa and 8.79 MPa or decreased by 1.3%, 24.7%, and 62%, compared to that without support plate. The same thing was also experienced by steel joints. In steel joints without support plates, the average shear strength was 21.59 MPa, and with the addition of steel support plates at L = 3.125 mm, the average shear strength decreased to 13.29 MPa or decreased by 38% compared to without support plates. This is higher than the aluminium single lap joint at the same L = 3.125 mm, indicating that the high modulus of the support plate reduced the decreased joint strength (Sugiman, 2022). Those results contradict the study of Demir et al. (2020), who reported an increase in failure load with the presence of support plates in SLJ. However, they used a longer overlap length (25 mm) where the possibility of bending is high. SLJ with a shorter overlap length (12.5 mm), where the shear stress is more dominant than the longer overlap length, may not experience what was reported by Demir et al. (2020). Abbasi et al. (2023) also pointed out that the longer the overlap length, the shear stress decreased, but the peel (normal) stress increased. This indicates that the bending moment at longer overlap length increased, resulting in higher peel stress. The support patches are likely effective for reducing peel stress in longer overlap, which leads to increasing the strength, as reported by Demir et al (2020). For a short overlap, in this case 12.5 mm, the shear stress dominated over the peel stress. Furthermore, the epoxy adhesive used here is not as rigid as that used by Demir et al. (2020); therefore, it is not capable of sustaining high shear stress as a rigid adhesive. Adding support plates on the SLJ increases the shear stress, and it is not suitable for low adhesive's modulus elastic, as the joint strength decreases.

3.2 Failure mode

After the specimen failure, the joint surface was observed with the naked eye and photographed with a camera. Most failures for all joints occurred cohesively in the adhesive layer, as seen in Figure 5. This shows that adhesive and adherend adhesion was good.

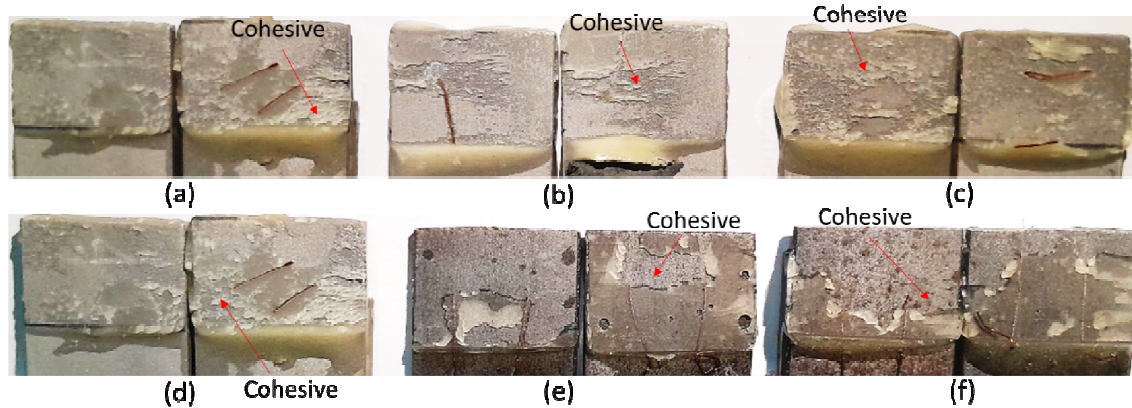


Figure 5. Failure mode in the adhesive layer of aluminium joints (a) without aluminium backing plate, with aluminium support plate on (b) $L=12.5$ mm, (c) $L=6.25$ mm, (d) $L=3.125$ mm. The failure mode of the steel joint (e) without the steel support plate and (f) with the steel support plate at $L=3.125$ mm.

3.3 FEM results of SLJ

3.3.1 Stress contours

Figure 6 shows the stress contour of von Mises in an aluminium single lap joint without a support plate and with a support plate ($L=6.25$ mm), with a load of 1000 N. The figure shows that in both the joint without and with the support plates, the highest stress occurs at the end of the joint because, in the area, there is a stress transfer from one adherend to another through the adhesive layer. Stress transfer can include normal stress and shear stress, but the shear stress is more dominant due to the eccentricity of the load. For SLJ with the support plate, it appears that the highest non-Mises stress decreases compared to SLJ without the support plate, from around 68 MPa to 49 MPa.

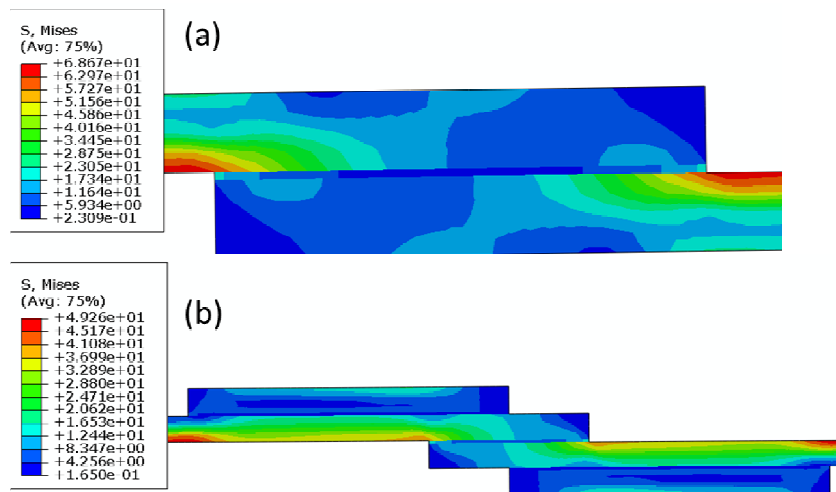


Figure 6. von Mises stress contour of SLJ (a) without support plate, (b) 6.25 mm aluminium support plate.

3.3.2 von Mises, shear (S12) and normal (S22) stress distribution

Figure 7 shows the stress distribution along the adhesive layer for von Mises stress, shear stress (S12) and normal stress (S22) at joints without and with aluminium backing plates at $L=12.5$ mm, 6.25 mm and 3.125 mm. For steel joints, the stress contour was only indicated without and with steel support plates at $L=3.125$ mm. From the figure, it can be seen that the addition of the support plate reduces the stress at the end of the joint, especially the support plate, which was placed at $L=6.25$ and 3.125 mm from the end of the joint. The support plate, which was placed at $L=12.5$ mm, does not have a significant effect on the von Mises stress at the end of the joint, even slightly higher than without the support. The stress at the end of lap for $L=12.5$ mm is higher than

that of without a support plate, indicating that the strength of $L=12.5$ mm should be lower than that of without a support plate. For the other L (6.25 dan 3.125 mm), the stress at the end lap is lower than that without a support plate. The decrease in stress at the end of the joint indicates a decrease in concentration, which will increase the shear strength of the joint. However, these results are inconsistent with the experimental results, as shown in Figure 4, where the shear strength is lower than without backing (support plates), which applies to aluminium and steel joints. Demir et al. (2020) showed that for an overlap length of 25 mm with $L=10$ mm, the addition of a support plate increased the joint strength by 54% compared to without a support plate. Numerically, the normal stress and shear stress are also lower than those without a support plate (see Figure 7b and c). The inconsistency of the experimental results and numerical results in this study and the contrast with the study by Demir et al. (2020) is likely due to the working stress mode. For joints with short overlap lengths, the shear stress is more dominant than the normal stress compared to the longer overlap length. Furthermore, numerically, the bond between substrate and adhesive was assumed to be perfect, and the flaws in the adhesive were not considered. The FEM also only considered the behaviour of substrates and adhesive was elastic and did not model the damage progression of the adhesive layer. In fact, those factors affect the joint strength. Further research is needed to investigate the effect of overlap length with and without a support plate on the strength of SLJ. For an overlap length of 12.5 mm, the shear and normal stresses are shown in Figures 7b, and c. It can be seen that the average shear stress is higher than the normal stress. Shear stresses work across the entire overlap length, but normal stresses occur only at the ends of the joints. The trend of normal and shear stress magnitude follows the von Mises stress trend with the addition of support plates.

For steel joints, the von Mises, shear and normal stresses are lower than in aluminium joints in the same case. This is because the elastic modulus of steel adherend is higher than that of aluminium adherend, so the stress transfer occurs better than that of aluminium.

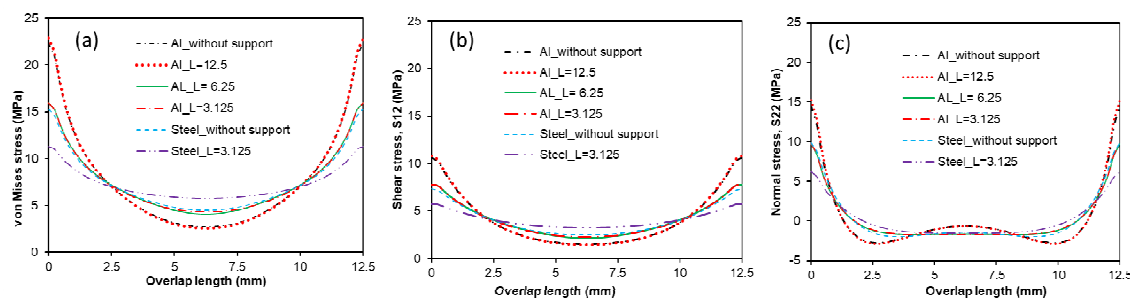


Figure 7. Comparison of stress distributions obtained from numerical analysis (a) von Mises, (b) shear (S12), and normal (S22) stresses on aluminium joints and steel joints without and with support plates.

4. CONCLUSION

Research has been conducted on the effect of adding support plates on the strength of aluminium shear joints and steel shear joints with Araldite adhesives, with an overlap length of 12.5 mm. Based on the results of the study, it can be concluded that the addition of support plates cannot increase the strength of aluminium shear joints, but tends to decrease the shear strength. The finite element modeling results show that the addition of a support plate decreases the von Mises stress, shear and normal at the end of the joint compared to the joint without a support plate. The stress drop indicates an increase in the shear strength of the joint. This contradicts the experimental results, which may be due to the fact that for short overlap lengths (12.5 mm), the dominant shear stress is not the cause of the initial failure, compared to the normal stress. However, this study has the limitation that the finite element method uses only the elastic conditions of substrates and adhesives. When a failure occurs, the substrate or adhesive experiences plasticity. It is not involved in the finite element method. Further research is needed to investigate the effect of the addition of support plates with overlap length variations.

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