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Investigation on the effect of non-uniform flash land on material redistribution in closed die forging with flash

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The objective of this study is to investigate the impact of non-uniform flash land on material redistribution during closed-die forging with flash, focusing on how the use of non-uniform flash land can increase the fullering coefficient and thereby reduce the number of forging steps required. The methodology combines theoretical analysis with finite element methods, varying the geometries of both the flash land and the billet, and comparing the results obtained from these different configurations. A comparison of forming results across four different billet specifications reveals that as the initial billet cross-section increases, the material transfer rate decreases. This is primarily due to the increased material volume in the region, which reduces material transfer and enhances cavity filling rate. However, increasing the billet cross-section also leads to a decrease in the fullering coefficient and an increase in the number of forging steps required. The study also shows that non-uniform flash land, especially non-uniform flash land 3, significantly improve the fullering coefficient, reaching 1.56, an 11.4% improvement over the traditional flash land coefficient of 1.4. This enhancement reduces the number of forging steps and improves the cavity filling rate. The forming load is positively correlated with the fullering coefficient, and under identical conditions, non-uniform flash land result in a forming load that is approximately 7.6% lower than that of traditional flash land. This reduction in forming load contributes to lower energy consumption and greater process efficiency. Moreover, non-uniform flash land demonstrate a distinct advantage in axial material redistribution and cavity filling. The enhanced axial material redistribution associated with non-uniform flash land promotes more uniform cavity filling, significantly reducing the occurrence of incomplete filling, especially when the fullering coefficient exceeds 1.4. This highlights the ability of non-uniform flash land to improve the quality of forged parts by minimizing the need for excessive forging steps while optimizing material usage. In conclusion, the findings emphasize the effectiveness of non-uniform flash land in optimizing axial material redistribution, improving cavity filling rate, and increasing the overall efficiency of closed-die forging processes. These benefits contribute to the production of higher-quality forged parts, with reduced energy consumption and fewer forging steps.

Key words: Closed-Die Forging With Flash, Non-uniform Flash, Fullering Coefficient, Cavity Filling Rate, Material Redistribution.

Inrtoducion

Closed die forging with flash is the most common method of bulk forming processes. And the flash land directly affects the number of forging steps required and the production cost [1–2]. The traditional flash land, due to its limited influence on material redistribution during forging, is not well-suited for complex forgings with significant cross-sectional variations. In contrast, the non-uniform flash land demonstrates excellent material accumulation capability, enhancing the material fullering coefficient while ensuring high forming quality [3].

The variable gutter technique, a novel approach to minimizing waste in closed-die forging, was investigated by M. Pourbashiri [4] for parts requiring vertical material flow. Case studies demonstrated up to a 50% reduction in waste, and finite volume method (FVM) simulations confirmed its effectiveness, underscoring that gutter thickness had the most significant impact on material flow. In another study, M. Sedighi et al. [5] analyzed a "T-shaped" part, exploring techniques involving variable gutter width and thickness. These approaches reduced material waste by 12% and 14%, respectively, with experimental tests aligning closely with simulation results for variable gutter thickness. Klawitter et al. [6] successfully employed different values of gutter height and width across different sections of a forged part, reducing the required forming force and enhancing cavity filling. Additionally, Hu et al. [7] optimized a two-step forging process for duplex forks, applying unequal thickness flash to prevent defects. Cracks stemming from the complex geometry of the fork were analyzed via finite element simulations, which identified non-uniform velocity distribution as a potential cause. Sheikhbahaee et al. [8] utilized 2D finite element simulations and response surface methodology to obtain the optimal dimensions for the dies and preform, including the width and thickness of the flash gutter and the amount of flash at each major cross-section.

Although non-uniform flash land has been applied in closed die forging with flash, a clear understanding of its effect on material redistribution remains lacking, presenting significant challenges for die design. Therefore, this research will investigate the effects of non-uniform flash land on material redistribution during the forging process.

2. The design methods for traditional flash land

The main dimensions of the flash land are height (h) and width (b). Traditional design approaches include the tonnage method and the calculation method. In the tonnage method, the geometry of flash land is first determined based on the forging and forming process characteristics, then the gutter dimensions are selected using an equipment tonnage reference table. This method relies heavily on accumulated production experience and lacks quantitative analysis. Another approach is the empirical formula calculation method, where common calculation formulas are as follows [9–11]:

$$h = 0.015\sqrt{A_n} \tag{1}$$

$$h = 0.0017D + \frac{1}{\sqrt{D}+5}$$
$$\frac{b}{h} = \frac{30}{\sqrt[3]{D\left[1+2D^2/h\left(2R+D\right)\right]}} \tag{2}$$

$$h = 1.13 + 0.089\sqrt{m} - 0.017m$$
$$\frac{b}{h} = 3 + 1.25\exp\left(-1.09m\right) \tag{3}$$

$$h = 0.016D$$
$$\frac{b}{h} = \frac{63}{\sqrt{D}} \tag{4}$$

where h - the height of flash land,
b - the width of flash land,
A_n - the projected area on the parting surface of the forging,
D - the maximum diameter or width of the forging,
m - the mass of the forging.

The traditional flash land belongs to the category of uniform flash land, characterized by identical structural features around the die, with even width and height often remaining constant. Uniform flash land generate consistent resistance around the die, which limits their ability to regulate the axial distribution of material effectively. Therefore, the cross-section of the forgings before and after forging cannot differ significantly, leading to an increased the number of forging steps required.

In contrast, non-uniform flash land can effectively address this issue. By introducing variations in resistance around the die, they enable better regulation of the axial distribution of material. Therefore, studying the influence of non-uniform flash land on the axial redistribution of material is of significant importance.

3. Methodology

The methodology used in this research combines theoretical analysis with finite element methods, altering the geometries of both the flash land and the billets, and compares the results obtained from these different geometries.

3.1. The design of billets specifications

In order to eliminate the influence of the billet, four different billets specifications were designed for comparative analysis. the specifications of billets are designed, as shown in Tab. 1:

Table 1

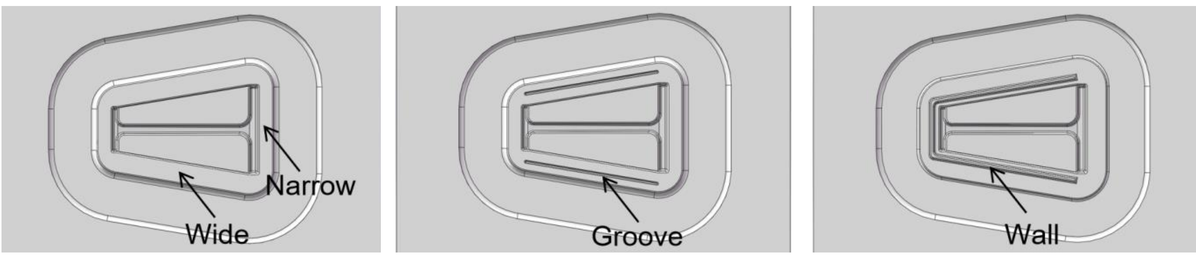
The specifications of billets

No.	D/mm	L/mm	fullering coefficient
1	15.12	58.5	1.56
2	15.67	54.4	1.50
3	16.28	50.5	1.45
4	16.96	46.5	1.40

Where, D= Square billet side length; L= Billet length; F= fullering coefficient.

3.2. The design of non-uniform flash land

To better investigate the effect of non-uniform flash land on material redistribution, three types of non-uniform flash land were designed: non-uniform flash land 1 (a), non-uniform flash land 2 (b), and non-uniform flash land 3 (c), as shown in Fig. 1. Specifically: The land width of non-uniform flash land 1 is various around its die. The non-uniform flash land 2 features resistance grooves within the land. The non-uniform flash land 3 incorporates resistance wall within the land.



a b c

Fig. 1 Non-uniform flash land:
a - flash land 1, b - flash land 2, c - flash land 3

3.3. Material redistribution

By taking 12 sections at equal distances along the axial direction, it is found that the material distribution of the forging specimen along the axial direction changes dramatically, with the maximum cross-sectional area ratio as high as 2.4, which is much greater than the difference in the other direction, as shown in the Fig. 2. Therefore, it is essential to explore the axial redistribution of the material.

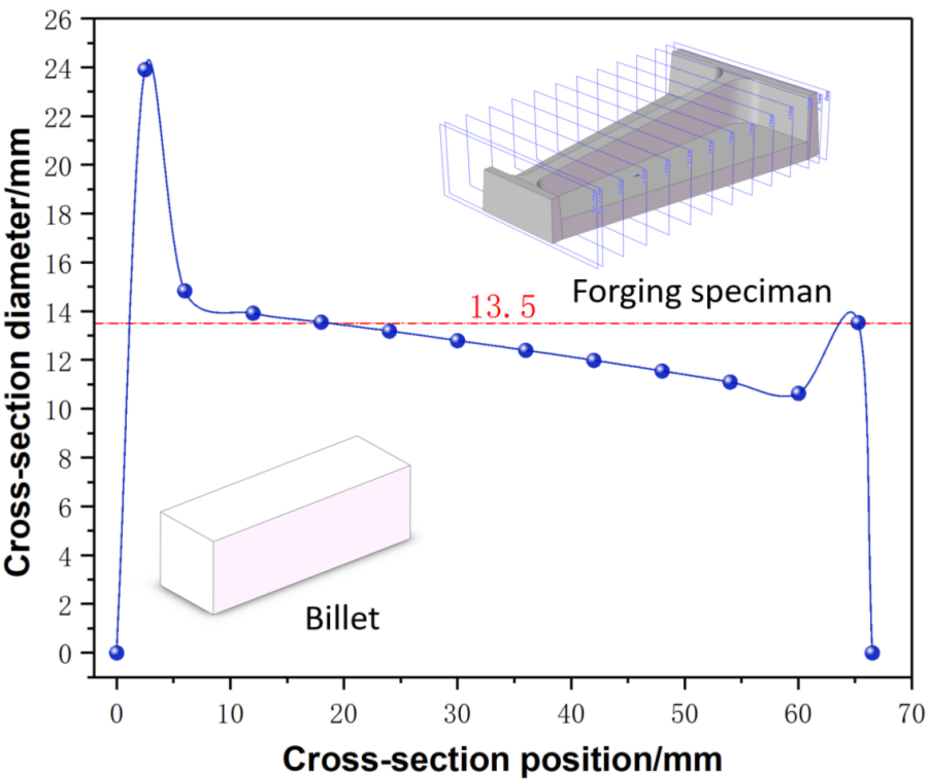


Fig. 2 Axial distribution of forging materials

In order to facilitate the study of the axial material redistribution during forging, the centerline of the forging along the axial length is divided into two parts. Define the cavity axial centerline (red line) as the material transfer boundary for pats 1 and 2, see Fig. 3.The material transfer rate obtained by comparing the changes in the amount of material in the two parts before and after forging. Since the dead zone is located in part 2, we mainly focus on the transfer rate of materials in the part 2 before and after forging. The calculation formula is as follows:

$$\delta = \left(V_{after} - V_{before} \right) / V_{before} \times 100\% \quad (5)$$

where, V_{aftrer} - The volume of material located in part 2 after forging, V_{before} – The volume of material located in part 2 before forging.

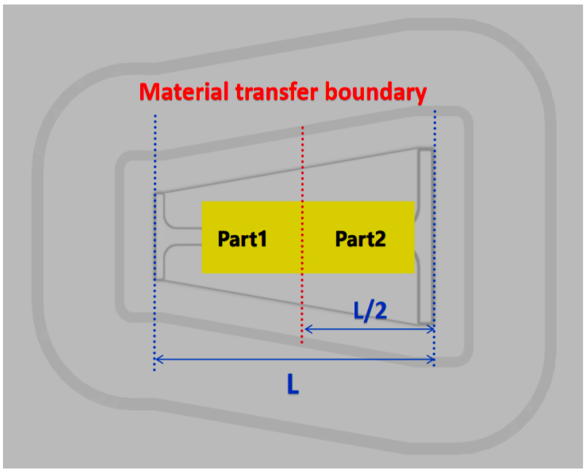


Fig. 3 Material transfer boundary

4. Results and discussion

4.1. Forming process analysis

As illustrated in Fig. 4, the forming process can be divided into three main stages. The first stage is the free upsetting stage, characterized primarily by upsetting deformation, during which part of the material begins to flow toward rib zone, keeping the forming load relatively low. The second stage is the extrusion forming stage; by this point, some material has already flowed into the flash land around the die, increasing resistance and causing material to flow toward dead zone. This results in a notable rise in the forming load.The third stage is the closure stage, when the upper and lower die surfaces are in contact and the excess metal flows to the flash land.

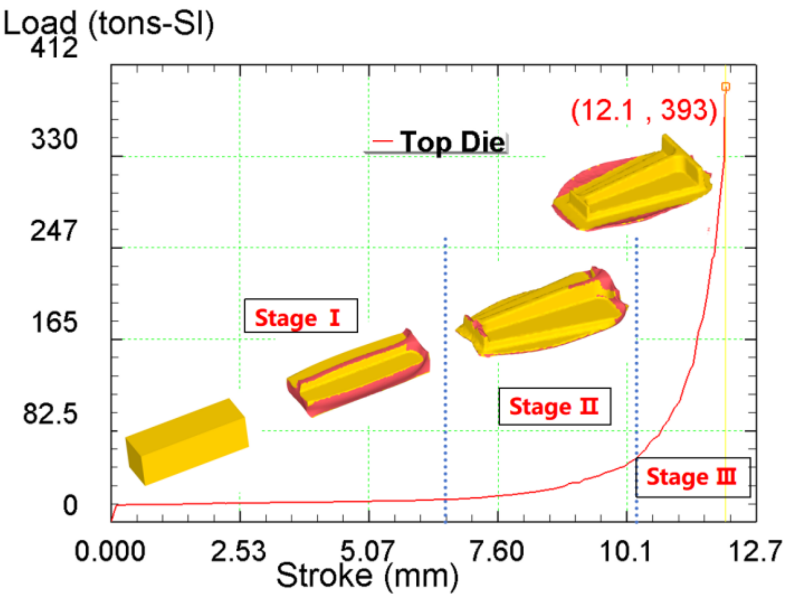


Fig. 4 Forging process analysis

4.2. Comparison of different billets

A comparison of forming results across four different billet specifications shows a declining trend in material transfer rates in part 2 as the cross-section of initial billet decreases, as illustrated in Fig. 5 . This decline primarily results from the increased initial billet volume positioned in part 2. Therefore, increasing the billet cross-section boosts the initial material volume in this region, effectively reducing material transfer and promoting complete cavity filling. However, the increase in cross-section of initial billet is bound to cause a decrease in the fullering coefficient, and increasing the number of forging steps required.

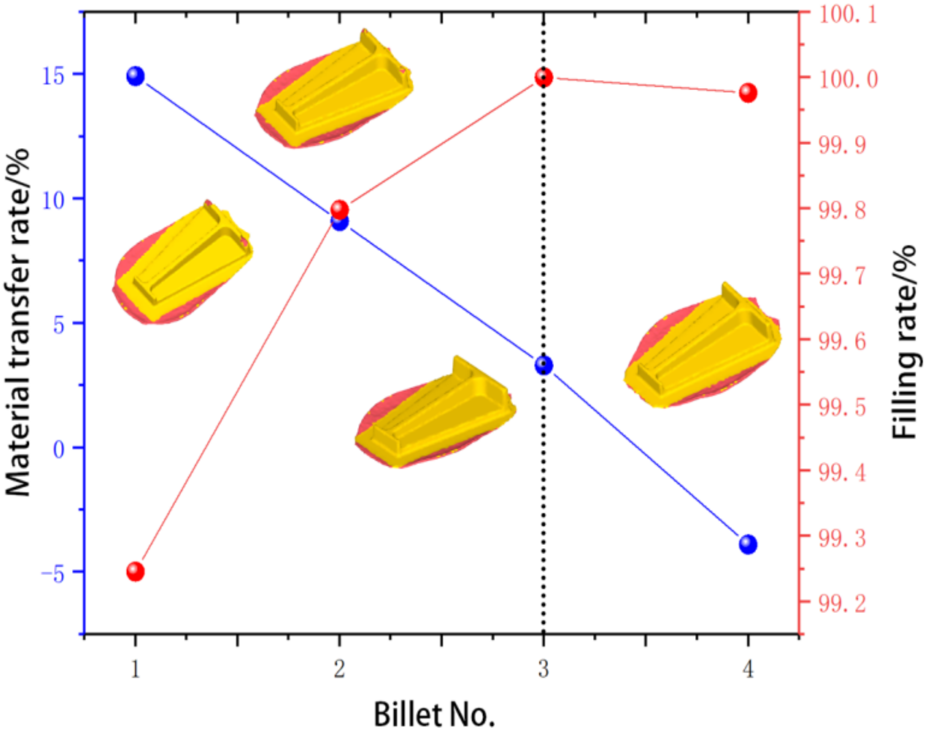


Fig. 5 The comparison of material transfer rate and cavity filling rate

4.3. The influence of the non-uniform flash land on the material redistribution

By comparison, it was observed that with the increase in the fullering coefficient, the cavity filling rate showed a significant decline, as shown in Fig. 6. This phenomenon is attributed to the differences in the axial material distribution between the billet and the final forging. Consequently, a higher fullering coefficient results in a reduced the number of forging steps required. At the same fullering coefficient, the cavity filling rate of non-uniform flash land was significantly higher than that of traditional flash land. This indicates that non-uniform flash land can effectively improve the axial redistribution of material during forging, thus enabling an increase in the fullering coefficient. In terms of the ability to redistribute axial material: Non-uniform flash land 3 > Non-uniform flash land 2 > Non-uniform flash land 1 > Traditional flash land. The traditional flash land had the least influence on axial material redistribution. When F > 1.4, the cavity began to exhibit incomplete filling. Non-uniform flash land 1 and 2 slightly outperformed the traditional flash land. However, non-uniform flash land 3 demonstrated a significant improvement in axial material redistribution, ensuring 100% cavity filling even at F = 1.56. Therefore, adopting non-uniform flash land can effectively increase the fullering coefficient and reduce the number of forging steps required.

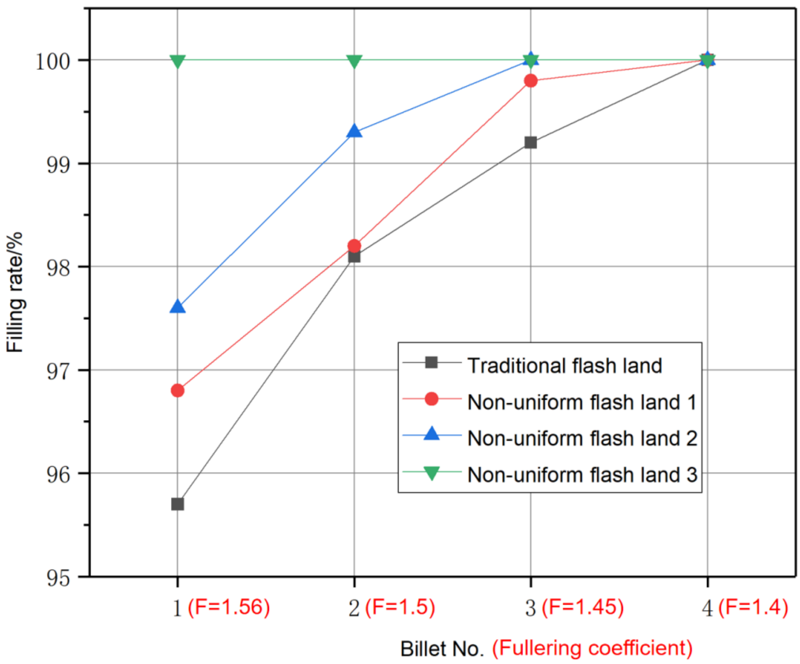


Fig. 6 Comparison of different flash land

4.4. Velocity field analysis

As shown in Fig. 7, the material flow velocity in zones 1, 2, and 3 around part 1 is significantly lower, while the flow velocity of material in the direction of the flash land near part 2 is noticeably higher than that around part 1. This indicates that the flow resistance around part 1 is significantly greater than that around part 2. Such a distribution facilitates the flow of excess material from part 1 to part 2 during the initial forging stage, rather than toward the flash land.

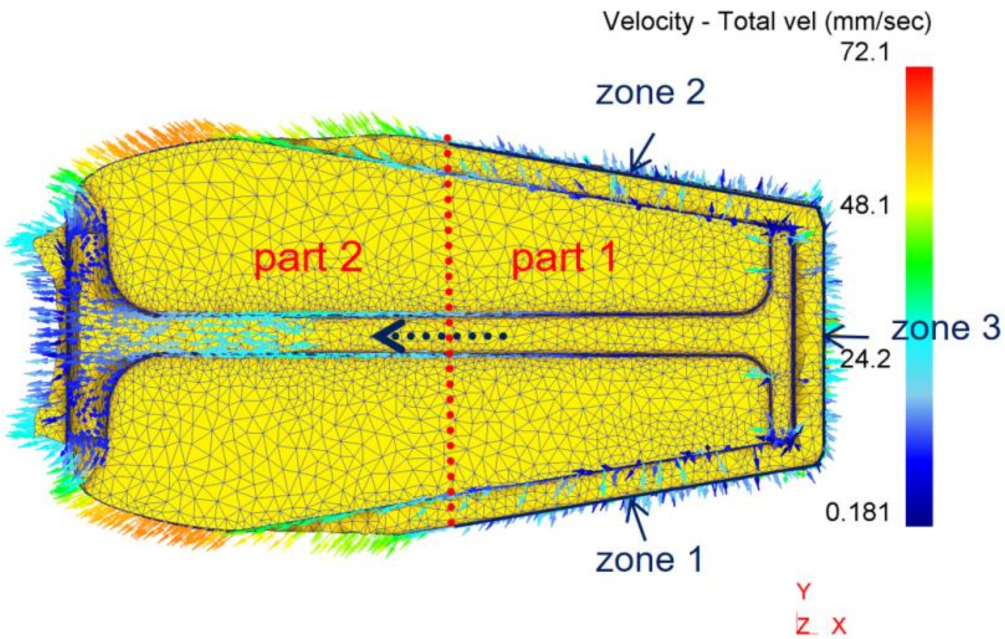


Fig. 7 The velocity field of non-uniform flash land 3(@stroke10.4mm)

4.5. Load analysis

The analysis revealed that the forming load is positively correlated with the fullering coefficient. Notably, under the same fullering coefficient, the forming load of non-uniform flash land is generally lower than that of traditional flash land, as shown in the Fig. 8. Under identical conditions, the forming load of non-uniform flash land is approximately 7.6% lower than that of traditional flash land.

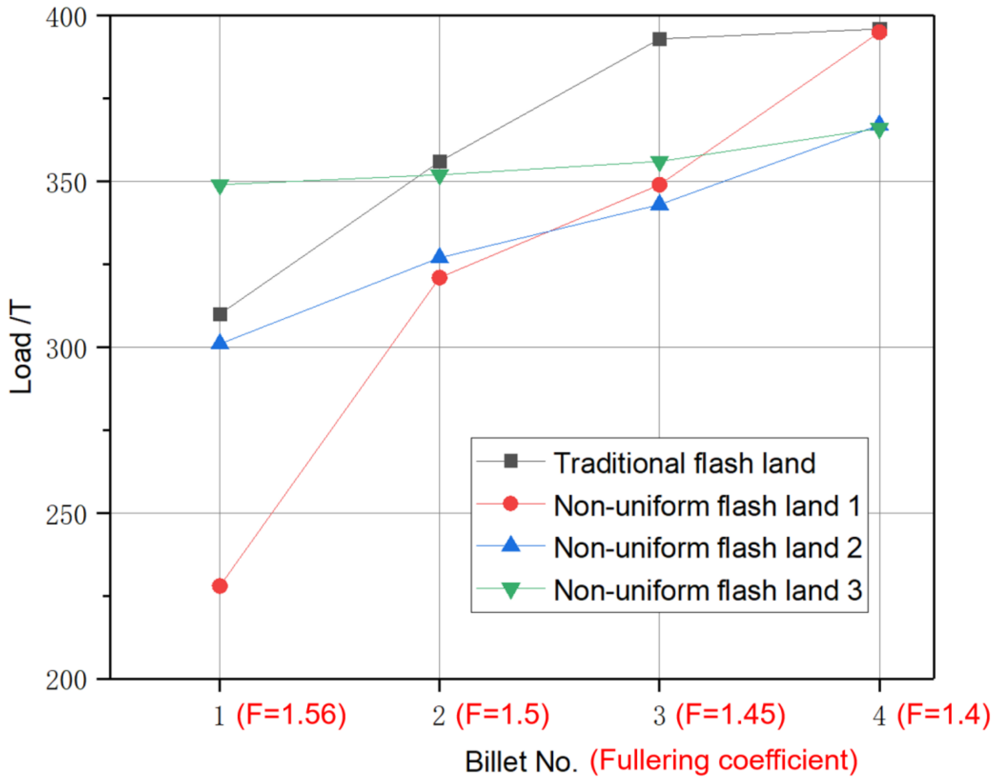


Fig. 8 Load analysis

Discussion

The objective of this study is to investigate the impact of non-uniform flash land on material redistribution during closed-die forging with flash, with a focus on how to use non-uniform flash land to increase the fullering coefficient and thus reduce the number of forging steps required. Through the preceding analysis, it was found that the material transfer rate is negatively correlated with the cavity filling rate, and demonstrating the significant impact of non-uniform flash land on material redistribution during the forging process. Non-uniform flash land 3 effectively increased the fullering coefficient to 1.56, representing an 11.4% improvement compared to the 1.4 achieved by traditional flash land. This improvement significantly reduces the number of forging steps required. Moreover, under identical conditions, the forming load of non-uniform flash land is approximately 7.6% lower than that of traditional flash land.

5. Conclusion

1. The study demonstrated that non-uniform flash land significantly influence axial material redistribution during the closed-die forging process. The use of non-uniform flash land, particularly non-uniform flash land 3, effectively improved the

fullering coefficient, reaching 1.56. This represents an 11.4% improvement over the 1.4 achieved by traditional flash land, which leads to a reduced the number of forging steps required.

2. The forming load was found to be positively correlated with the fullering coefficient. Under identical conditions, the forming load associated with non-uniform flash land was approximately 7.6% lower than that of traditional flash land. This reduction in forming load contributes to lower energy consumption and improved overall process efficiency during forging.

3. Non-uniform flash land showed a clear advantage in terms of axial material redistribution and cavity filling rate. With higher axial material redistribution, non-uniform flash land promoted more uniform filling of the cavity, reducing the occurrence of incomplete filling, especially when the fullering coefficient exceeded 1.4. This highlights the potential of non-uniform flash land in improving the quality of forged parts by minimizing the need for excessive forging steps while optimizing material usage.

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Дослідження впливу нерівномірного облойного містка на перерозподіл матеріалу при штампуванні в відкритих штампах з облоєм

Метою цього дослідження є вивчення впливу нерівномірних облойних містків на перерозподіл матеріалу під час штампування у відкритих штампах з облоєм, з акцентом на те, як використання нерівномірних облойних містків може збільшити коефіцієнт попереднього розплющення та, відповідно, зменшити кількість необхідних етапів штампування. Методологія поєднує теоретичний аналіз з методом кінцевих елементів, варіюючи геометрію як облойного містка, так і заготованки, і порівнює результати, отримані за різних конфігурацій. Порівняння результатів формоутворення для чотирьох різних специфікацій заготованок показує, що зі збільшенням початкового поперечного перерізу заготованки швидкість перенесення матеріалу зменшується. Це зумовлено збільшенням об’єму матеріалу в області, що знижує перерозподіл матеріалу та покращує заповнення порожнини. Однак зі збільшенням поперечного перерізу заготованки коефіцієнт попереднього розплющення зменшується, а кількість необхідних етапів штампування зростає. Дослідження також показує, що нерівномірні облойні містки, особливо нерівномірний облойний місток №3, значно покращують коефіцієнт попереднього розплющення, досягаючи значення 1,56, що на 11,4% більше, ніж традиційний коефіцієнт облоя 1,4. Це покращення зменшує кількість етапів штампування та підвищує швидкість заповнення рівчака. Формувальне навантаження позитивно корелює з коефіцієнтом попереднього розплющення, і за однакових умов нерівномірний облойний місток забезпечує формувальне навантаження приблизно на 7,6% нижче, ніж традиційний облойний місток. Це зниження навантаження сприяє зменшенню енергоспоживання та підвищенню ефективності процесу. Крім того, нерівномірні облойні містки демонструють явну перевагу у осьовому перерозподілі матеріалу та заповненні рівчака. Покращений осьовий перерозподіл матеріалу, пов'язаний із нерівномірними облойними містками, сприяє більш рівномірному заповненню рівчаків, значно зменшуючи ймовірність недозаповнення, особливо коли коефіцієнт попереднього розплющення перевищує 1,4. Це підкреслює здатність нерівномірних облойних містків покращувати якість штампованих деталей, мінімізуючи потребу в надмірній кількості етапів штампування та оптимізуючи використання матеріалу. Таким чином, результати дослідження підкреслюють ефективність використання нерівномірних облойних містків для оптимізації осьового перерозподілу матеріалу, покращення швидкості заповнення рівчаків і підвищення загальної ефективності процесів штампування у відкритих штампах. Ці переваги сприяють виготовленню більш якісних штампованих деталей, зменшенню енергоспоживання та скороченню кількості етапів штампування.

Keywords: штампування у відкритих штампах з облоєм, нерівномірний облойний місток, коефіцієнт попереднього розплющення, швидкість заповнення рівчаків, перерозподіл матеріалу.

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