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Influence of dent on residual ultimate strength of 2024-T3 aluminum alloy plate under axial compression

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Abstract: Drop-weight impact tests were conducted on 2024-T3 aluminum plates with five types of impactors, and then the effects of the dent on the residual ultimate strength of the 2024-T3 specimens were investigated through axial compression tests. Results indicate that with increase in dent depth, the five types of dents affect the ultimate strength of the plate in different trends. Nevertheless, other than the plate global deflection caused by impacting, the dent itself has unremarkable effect on the ultimate strength. The mathematical expressions are derived regarding the relationship between impact energy factor and the dent depth factor as well as the compressive ultimate strength reduction rate and the dent depth factor.

Key words: aluminum alloy plate; impactor; dent; residual ultimate strength; compression

1 Introduction

Various damages may occur throughout the lifetime of the aircraft. Foreign object damage (FOD) is one of the typical types and it is the primary cause of fatigue failure or the loss of ultimate strength of the fuselage skin panels. When the skin panels are impacted by foreign objects, the hole, crack, or dent will be produced, in which the hole/crack is impacted by the subjects (e.g. the bird) at very high speed/energy level with removal of material, while a dent is impacted by a subject (e.g. the stone) at a low velocity/energy level without removal of material or change in cross-sectional area. At present, numerous studies are available in the literature with regard to the process of the plates impacted by the objects at very high impact velocity [1−4] and the loss of fatigue and ultimate strength of plates with imperfections like cracks and holes [5−7]. However, to the best knowledge of the authors, very few studies focused on the effect of the dent on the residual ultimate strength of the plate, especially the aluminum alloy plate.

DOW and SMITH [8] investigated the buckling and post-buckling behaviors of rectangular plates with localized initial deformation under uniaxial longitudinal compression through numerical simulation. The results indicate that the influence of localized imperfections mainly depends on the amplitude and slightly relies on the shape and the location. PAIK et al [9,10] simulated the effects of dent size and plate global parameters on the ultimate strength of the dented steel plates under compression and shear conditions respectively. The simulation results show that the plate global parameters (i.e., thickness and aspect ratio) govern the collapse behavior of the plate rather than the local denting-induced behavior. LUIS and GUEDES SOARES [11] analyzed the effect of local imperfection and its position on the ultimate collapse behavior of steel plates subjected to compression and found that local imperfections significantly changed the strength of the panel when combined with the global ones. AN et al [12,13] proposed the expressions of the reliability

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calculation based on the ultimate strength reduction factor affected by dents. WITKOWSKA and GUEDES SOARES [14] studied the collapse behavior and ultimate strength of the dented stiffened steel panels. It is concluded that the stiffened panels with local dent demonstrate quite good performance and are not affected much by the damage. RAVIPRAKASH et al [15−17] numerically investigated the effect of dent orientation on the ultimate strength of square steel plates under uniaxial compression and their results show that the transverse dent affects the ultimate strength more drastically than the longitudinal dent. XU and BUEDES SOARES [18] assessed the residual ultimate strength for wide dented stiffened panels subjected to compressive loads and it is shown that the collapse behavior of stiffened panels depends on dent depth.

All of the above studies are about the residual ultimate strength of dented steel plates commonly used in the ships, whereas very limited studies are on the dented aluminum alloy plates. SHIVALLI [19] studied the effect of dent on the fatigue life of 2024-T3 aluminum plate and the crack growth, but the residual ultimate strength was not concerned in that study. GUIJT et al [20] conducted compression tests on the stiffened 2024-T3 aluminum alloy with or without dents. The results showed that the dents had no substantial effect on the structural stability. However, in that study, only one constant depth was assigned. LANG and KWON [21] numerically investigated the effect of the spherical dent on the compressive failure load of the 2024-T3 aluminum alloy. It was concluded that the shallow dents can decrease the ultimate strength and the dents with large depth can increase the failure load of the dented panel.

The above studies have shed light on uncovering the characteristics of the ultimate strength of the dented plates. However, few test data are available and the dent size/shape variation was not considered in the literature. To address the above problems, this study focused on 1) predicting the dent size (i.e., depth, width) impacted by different types of impactors at multiple level energies; 2) investigating the effects of residual ultimate strength of aluminum alloy plate by the dents with different sizes and shapes. The results of this study can provide validation on analytical modeling of the dented aluminum plate.

2 Experimental

2.1 Specimen preparation

The 2024-T3 aluminum alloy plate, which is the most widely used material for aircraft skin, was chosen to conduct the impact and compression tests. The size/shape of the specimen is shown in Fig. 1(a). To mimic the dent shapes on the skins of actual aircraft, five types of impactors made of dead-hard steel were designed to strike the aforementioned aluminum alloy specimens, resulting in dents with different sizes and shapes. As shown in Fig. 1(b), these five types of dents were respectively named as spherical impactor (Type I), conical impactor (Type II), U-shape impactor (Type III), V-shape impactor (Type IV), and elliptical impactor (Type V).

2.2 Impact tests

A custom-designed drop tower setup which can equip with different types of impactor was used to provide dents as shown in Fig. 2. The maximal drop

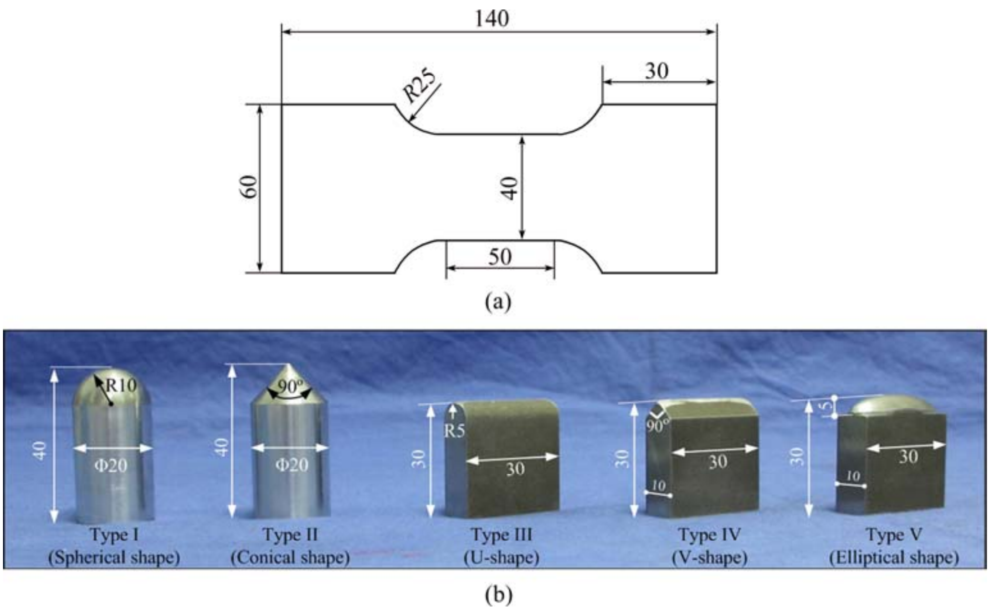

Fig. 1 Schematic diagram of 2024-T3 aluminum alloy specimen (a) and five impactors (b) (Unit: mm)

height and mass can reach 7 m and 200 kg respectively, with the maximal impact energy of approximately 14000 J. The impact energy of the drop tower can be modified by altering the drop height and/or the impact weight so as to produce dents with different depths. The impactor was installed at the bottom of the impact block which can drop down freely along the slide track and the central location of the specimen aligned with the axis of the impactor in the vertical direction, thus resulting in consistent dents. During the tests, the specimen was stably clamped to prevent from slipping. The impact acceleration was collected by an acceleration sensor.

An impact block equipped with impactor with the total mass of 13.4 kg was used. The dents with different shapes and depths were struck by varying the impactor and the drop height respectively. In this study, five types of impactors and four to five drop heights were involved, in which the maximal drop height was obtained once obvious cracks or hole was observed on the specimen during impacting. Three repeated tests were performed for each circumstance. The specified test matrix for different impactors and drop heights are tabulated in Table 1, with a total of 63 tests included.

2.3 Compression tests on dented aluminum alloy specimen

Axial compression tests were conducted on the dented aluminum alloy specimens as shown in Fig. 3. A CIMACH DDL50 universal test machine was used with an integrated load cell of 50 kN loading capacity. An industrial camera was used to record the deflection of the specimen. In the compression test, the specimen in the axial direction was simply supported, preventing the out of plane movements but allowing rotation. At beginning, tiny gaps were left between the compression plate and the specimen to prevent the initial deflection of the specimen, and then the compression plate gradually contacted and compressed the specimen at a constant low velocity of 1 mm/min.

When an intact specimen is struck by an impactor, the global deflection of the specimen also occurs besides the dent. In order to investigate only the effects of the dent on the ultimate strength of the specimen, the effects by the specimen's initial global deflection must be removed. Therefore, the intact specimens (without any dent or global deflection) and the specimens with only initial global deflections were also tested under the same conditions as the dented specimens. For the compression tests, three repeated experiments were performed respectively for the dented, pre-deflection and intact specimens.

3 Results

3.1 Drop impact tests

A total of 63 specimens were used to conduct the drop-weight impact tests. The dents caused by different impact energies and impactors are shown in Fig. 4. When the specimen is impacted by the impactor, the deformation area will be generated, including the dent and transition zones. The dent depth and the transition zone expand with the increase of drop height/impact energy. The critical heights at which obvious hole or crack can be caused in the specimens for the spherical, conical, U-shape, V-shape, and elliptical impactors, are 50 cm, 30 cm, 40 cm, 35 cm and 40 cm, respectively.

To quantify the variation of the dent damage features with the drop height/impact energy, several parameters were used to describe the size of different types of dents, as shown in the sectional views in Fig. 4. For the spherical and conical shape dents, because the impacted deformation area includes the dent at the impact point and transition zone, three geometrical parameters, dent global depth (H), dent regional depth (h) and dent regional width (w) at the impact point were used to describe the deformation of the impact area. For the U-shape, V-shape, and elliptical shape dent, only the dent global depth (H) was used because the dent zones at the impact point are very small. The average values and

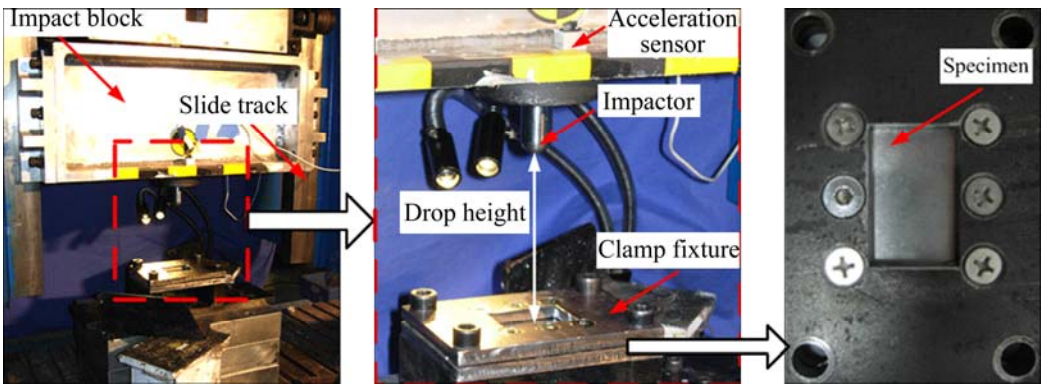

Fig. 2 Setup of drop-weight impact test

Table 1 Specification of drop impact tests

Impactor type	Drop height (m)/ Impact energy(J)	Number of specimen
Type I (spherical shape)	0.1/13	3
	0.2/26	3
	0.3/39	3
	0.4/52	3
	0.5/65*	3
Type III (U-shape)	0.1/13	3
	0.2/26	3
	0.3/39	3
	0.4/52*	3
Type V (elliptical shape)	0.1/13	3
	0.2/26	3
	0.3/39	3
	0.4/52*	3
Type II (conical shape)	0.1/13.	3
	0.2/26	3
	0.25/33	3
	0.3/39*	3
Type IV (V-shape)	0.1/13	3
	0.2/26	3
	0.3/39	3
	0.35/46*	3

*Represents the ultimate drop height and impact energy causing obvious crack or hole on the impacted specimen.

the standard deviations of the dent parameters under each impact condition for the 5 types of impactors were obtained. Figure 5(a) shows the relationship between W and H for the five types of dents. Figure 5(b) shows the relationship between W and h as well as W and w at the

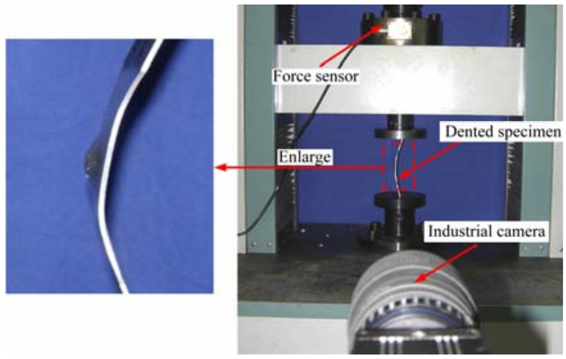

Fig. 3 Axial compression tests on specimen

impact point for spherical and conical dents. To normalize the parameters H, h, w, and W, dimensionless reduction factors of H ($RF_H = H/H_0$), h ($RF_h=h/h_0$), w ($RF_w=w/w_0$), W ($RF_W=W/W_0$) were defined, in which H_0, h_0, w_0, and W_0 represent the ultimate values of the dents and impact energies when obvious cracks or holes were caused on the plate. The regression formulas between RF_H and RF_W are listed from Eqs. (1) to (5) for the 5 types of impactors. It is seen that for the spherical, conical, and elliptical dents, RF_H changed linearly with the increase in RF_W. With increase in RF_W, the RF_H showed a logarithmic function increasing trend and a power function increasing trend for the U-shape and V-shape dent respectively.

$$RF_H=0.892RF_W+0.104,\ \text{spherical dent} \tag{1}$$

$$RF_H=0.860RF_W+0.152,\ \text{conical dent} \tag{2}$$

$$RF_H=0.510\ln(RF_W)+0.970,\ \text{U-shape dent} \tag{3}$$

$$RF_H=0.988RF_W^{1.062},\ \text{V-shape dent} \tag{4}$$

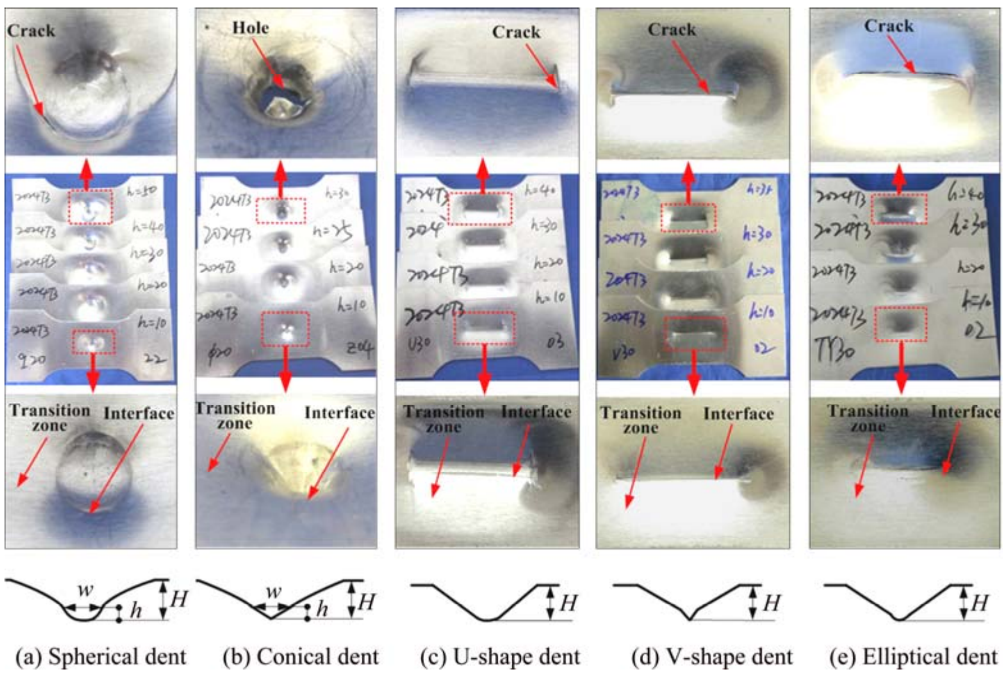

Fig. 4 Sizes/shapes and sectional views of five types of dents

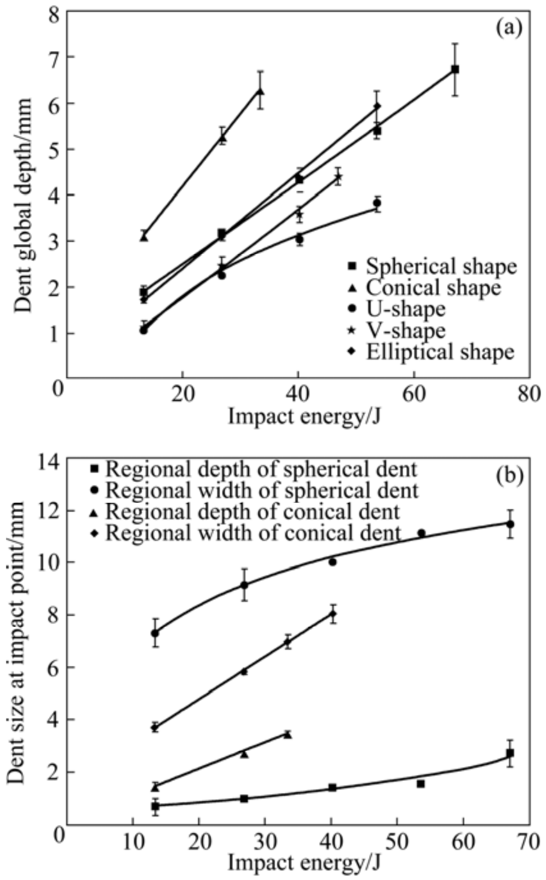

Fig. 5 Relationship between impact energy and dent size parameters: (a) Dent global depth; (b) Dent regional depth and width at impact point

RF_H=0.936RF_W+0.052, elliptical dent (5)

From Eqs. (6) to (9), it is seen that RF_h and RF_w at the impact point exhibit an exponential trend and a logarithmic function trend with RF_W respectively for the spherical dent. Whereas, for the conical dent, both RF_h and RF_w show approximately linear relationships with RF_W.

$RF_h = 0.193e^{1.568RF_W}$, spherical dent (6)

RF_w=0.228ln(RF_W)+1.002, spherical dent (7)

RF_h=0.962lnRF_W+0.038, conical dent (8)

RF_h=0.809RF_W+0.190, conical dent (9)

3.2 Compression tests on dented plate

Both the dent and the plate global deflection will be produced when the impactor impacts the aluminum alloy plate. Taking the spherical dent as an example, Fig. 6 shows the schematic diagram of the dent and the global deflection formed in the aluminum plate. The residual ultimate strength of the plate will be affected by both the dent and the global deflection. To investigate the effect of only the local dent on the residual ultimate stress of the plate, the effect of the global deflection caused by the denting should be removed from the combined dent and the global deflection.

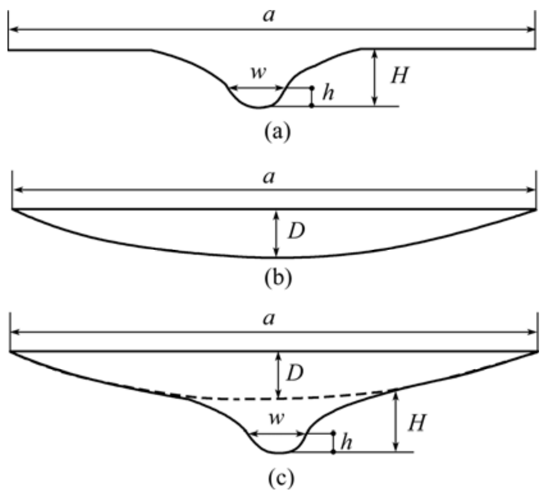

Fig. 6 Schematic diagram of spherical dent damage on plate: (a) Local dent; (b) Global deflection by denting; (c) Combined global deflection and dent

Test results showed that the deflected patterns and collapse behaviors are similar for the intact specimens, specimens with only global deflection, as well as the specimens with both dent and deflection. These specimens gradually bent from approximately the center of the specimen. However, for the dented specimens with holes or obvious cracks, the deflection will arise from the fracture locations due to these damages weakening the specimen at the surrounding area.

3.2.1 Effect of both dent and deflection on residual strength of plate

The results of the residual strength for the un-dented specimen and the five types of the dented specimens with different depths (*H*) and different global deflections (*D*) under axial compression are shown in Fig. 7, in which each curve was obtained by averaging the results of the three repeated tests. It is seen that, compared with the un-dented specimen, the ultimate strength of the dented specimen obviously decreased. The largest and the second largest ultimate strength reduction were observed for the conical and spherical dents, with the reduction rates equivalent about 50% and 40% respectively. For the other three types of dents, the reduction rates were 20%−30%. It should be stressed that the above ultimate strength reduction was functioned by both the local dent and the plate global deflection due to denting. Although the ultimate strength of the un-dented specimen is obviously higher than that of the dented specimens, a “collapse” behavior immediately came out for the un-dented (intact) specimen instead of the dented specimen when the ultimate strength was reached. The strength of the intact plate decreased approximately at

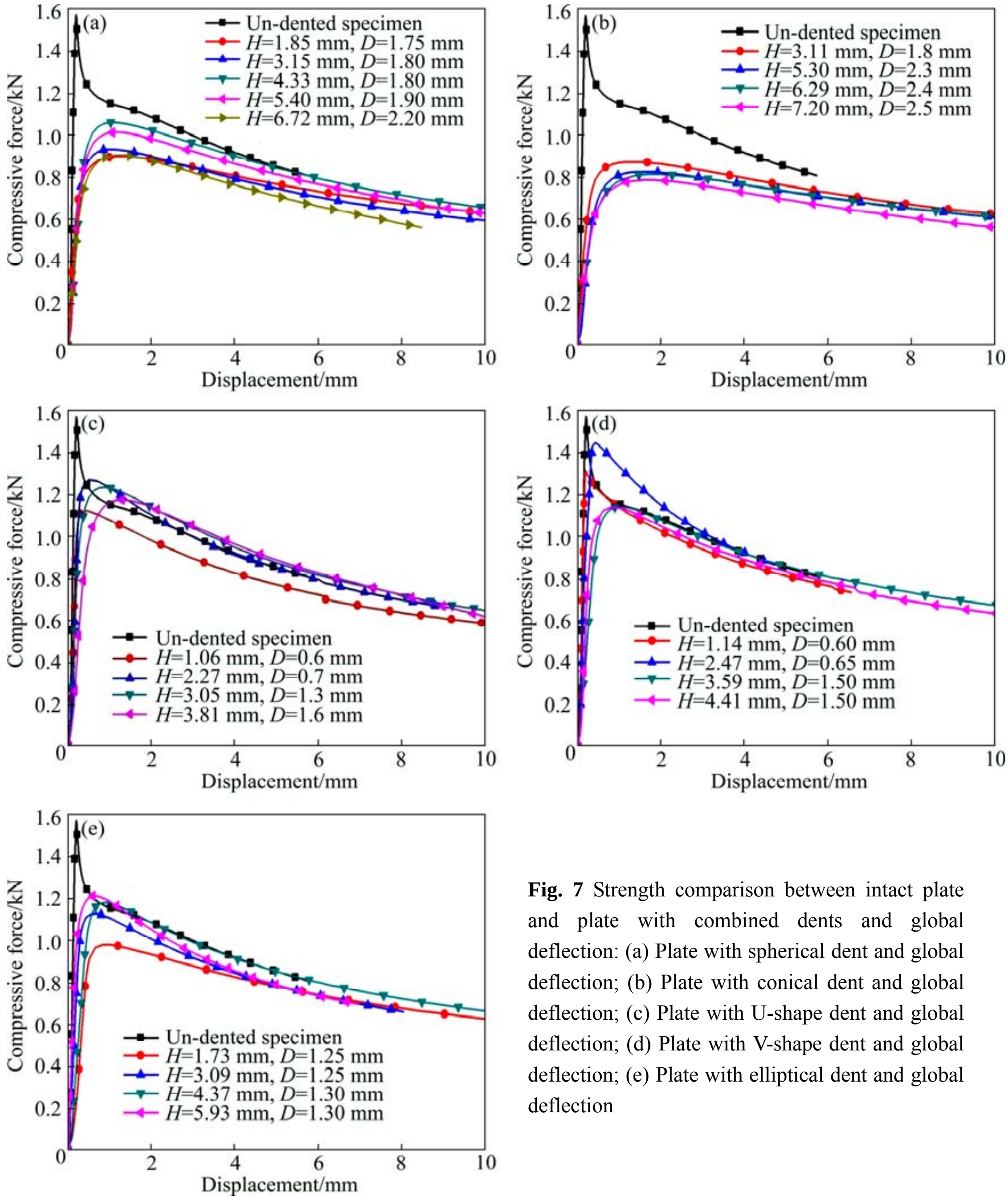

Fig. 7 Strength comparison between intact plate and plate with combined dents and global deflection: (a) Plate with spherical dent and global deflection; (b) Plate with conical dent and global deflection; (c) Plate with U-shape dent and global deflection; (d) Plate with V-shape dent and global deflection; (e) Plate with elliptical dent and global deflection

the same level with the plate with spherical or conical dent at the deflection of 6−7 mm. However, for the U-shape, V-shape, and elliptical dented plates the strength of the intact plate reached the same level with the plates with these three types of dents at the deflection of only 1 mm.

3.2.2 Effect of only global deflection on residual ultimate strength of plate

The effect of global deflection caused by the denting on the ultimate strength of the plate under compression should be studied prior to further investigating the effect of only the local dent. The global deflections of the plates caused by different types of impactors and impact energies were measured. Typical global deflection (D) values are 0.6, 1.5, 1.9, and 2.5 mm for most impact tests. Therefore, the intact plates were pre-deflected with above 4 values and used to conduct compression tests. Three repeated tests were conducted for each deflection value. The strength histories of the plates with these 4 typical global deflections as well as the intact plate are shown in Fig. 8(a). It is seen that the global deflection of the plate can significantly affect the compressive strength of the plate. For a plate with the deflection of 0.6 mm, the ultimate strength decreased by

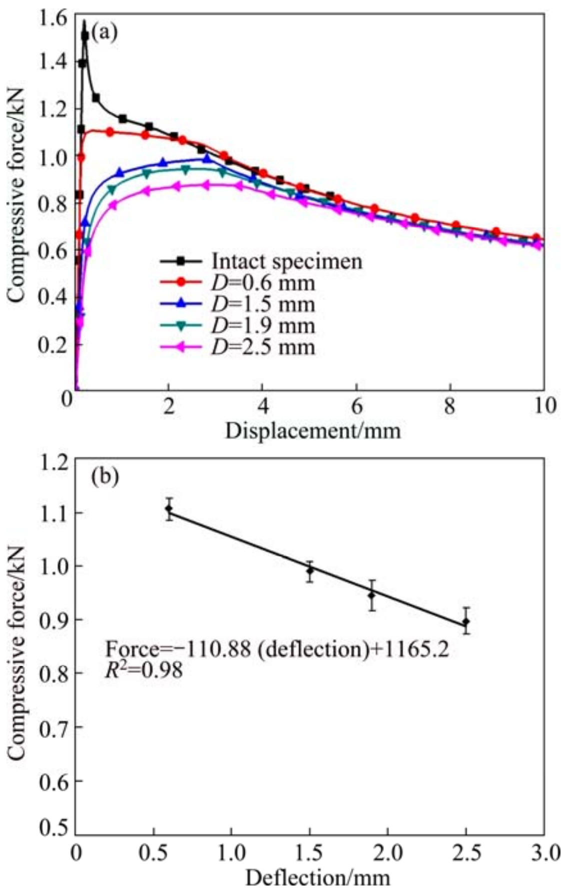

Fig. 8 Strength of aluminum plate affected by global deflection: (a) Strength comparison between intact plates and specimens with 4 typical global deflections; (b) Relationship between ultimate compressive force and global deflection

about 30% compared with the intact plate. It decreased by nearly 50% when the deflection increased to 2.5 mm. It is seen that only a small defection will cause large reduction of the compressive ultimate strength. The “collapse” behavior was not found for the specimen with only deflection, indicating that a small deflection can change the “collapse” behavior of the intact specimen, making the specimen’s strength decrease in a relatively flat slope.

The ultimate strengths for the specimens with the aforementioned 4 deflections were fitted in Fig. 8(b). A relatively high linear correlation was observed between the ultimate strength and the deflection (R^2=0.98). The ultimate strengths with deflections within 0.6 mm to 2.5 mm can be interpolated from Fig. 8(b).

3.2.3 Effect of only dent on residual ultimate strength of plate

The effect by both the dent and the global deflection can be considered superposition of the effect by only the dent and only the global deflection. To normalize the ultimate compressive strength of the dented plate and further compare it with the plate with only deflection, ultimate strength reduction rate (R_r) was defined as follows: R_r=(Ultimate strength of plate with only deflection − Ultimate strength of dented plate)/(Ultimate strength of plate with only deflection). A result greater than zero means the dent can weaken the ultimate strength of the specimen; otherwise, it will stiffen the ultimate strength.

Figure 9 shows the ultimate strength reduction rate affected by dent, global deflection, and both of them, in which the absolute values of the residual ultimate strengths were normalized to a value less than or equal to one by dividing them by the ultimate strength of the intact specimen. It is seen that the ultimate strength can be significantly decreased by the condition with only deflection and the condition with both dent and deflection. The ultimate strength reduction rates affected by only the different types of dents are shown in the rectangle dashed box from Fig. 9(a) to Fig. 9(e). In general, the reduction rates affected by only the dents are much lower than those affected by only the deflections and varied with different types of dents. For the spherical dent, the ultimate strength of the specimen first decreased at small dent depth, and then it began to ascend slightly with increasing the dent depth and the maximal increase rate is about 7%. However, when obvious crack around the dent occurred in the specimen (see Fig. 4), the ultimate strength began to decrease again. For the conical dent, due to the stress concentration, the specimen’s ultimate strength is reduced linearly with the dent depth, with the maximal reduction rate of about 7%. For the U-shape, V-shape, and elliptical dents, due to the fairly smooth shapes, they can stiffen the specimen and increase the ultimate strength in different characteristics before the hole or crack damage occurred. The ultimate strength increases with the dent depth in a quadratic, cubic and logarithm way for the U-shape, V-shape, and elliptical dents, with the maximal increase rate of approximately 14%, 24%, and 13% respectively.

The relationships between R_r and RF_H for different types of dents were regressed as follows respectively:

$$R_r = 0.560RF_H^2 - 0.781RF_H + 0.224, \text{ spherical dent} \quad (10)$$

$$R_r = 0.028RF_H + 0.038, \text{ conical dent} \quad (11)$$

$$R_r = 0.295RF_H^2 - 0.475RF_H + 0.058, \text{ U-shape dent} \quad (12)$$

$$R_r = -3.832RF_H^2 + 7.919RF_H^2 - 4.85RF_H + 0.668, \text{ V-shape dent} \quad (13)$$

$$R_r = -0.127\ln(RF_H) - 0.139, \text{ elliptical dent} \quad (14)$$

3.2.4 Comparison of compressive force−displacement history for specimen with only deflection and with combined dent and deflection specimens

Figure 10 illustrates the history of the compressive force-displacement curve under a typical compression

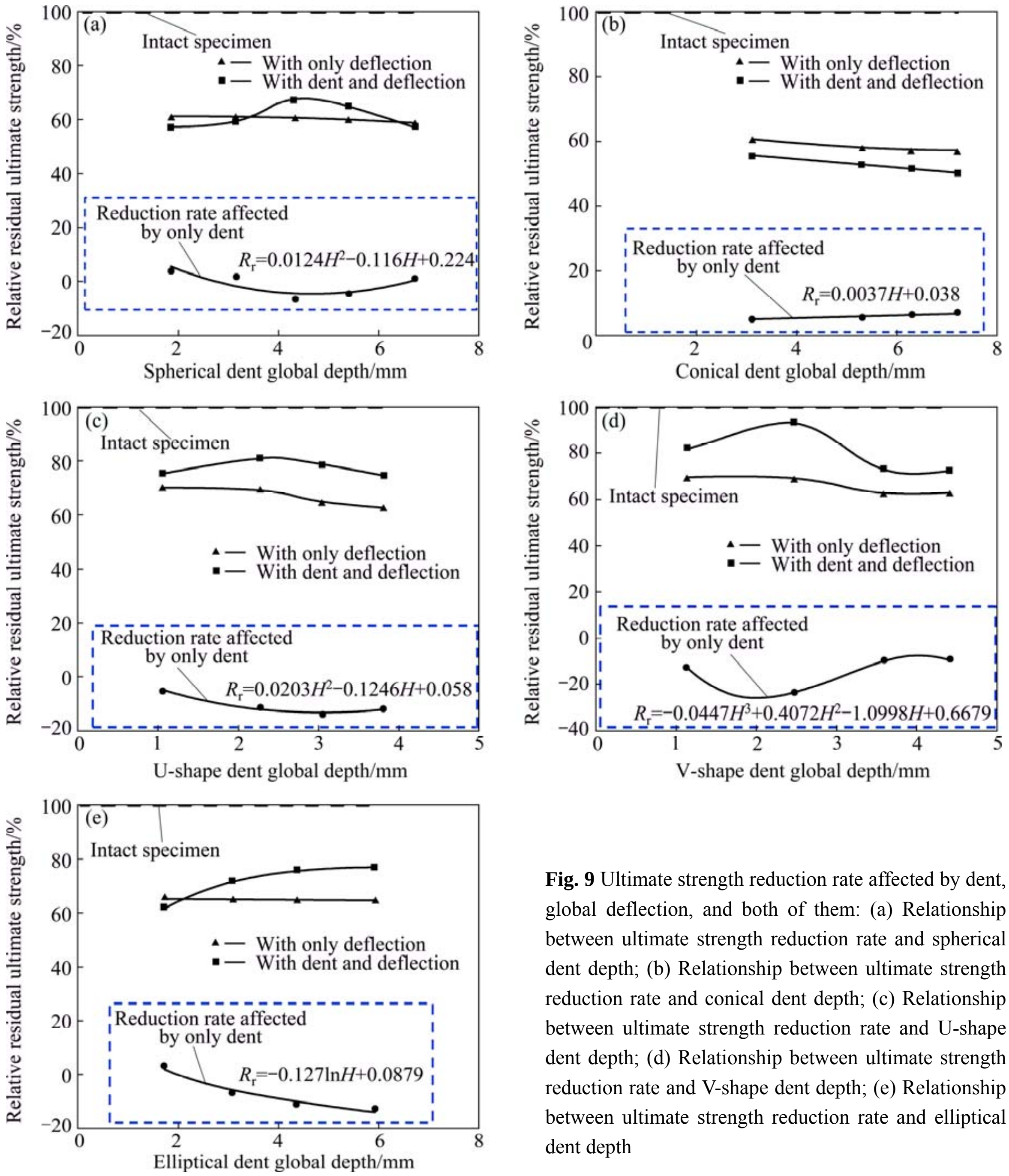

Fig. 9 Ultimate strength reduction rate affected by dent, global deflection, and both of them: (a) Relationship between ultimate strength reduction rate and spherical dent depth; (b) Relationship between ultimate strength reduction rate and conical dent depth; (c) Relationship between ultimate strength reduction rate and U-shape dent depth; (d) Relationship between ultimate strength reduction rate and V-shape dent depth; (e) Relationship between ultimate strength reduction rate and elliptical dent depth

condition. To represent the characteristics of the compression displacement for the maximal strength and the duration from a given value (e.g. 80% of the maximal strength) to the maximal strength as well as from the maximal strength to a given value for the intact, with only deflection, and with combined dent and deflection specimens, 5 parameters, D_1, D_2, D_3, ΔD_F, and ΔD_R were defined, in which D_2 represents the compressive displacement where the maximal strength occurred; ΔD_F and ΔD_R represent the compressive displacement duration from 80% of the maximal force to the ultimate strength and the duration from the maximal strength attenuating to 80% of the maximal strength respectively. A higher value of ΔD_F or ΔD_R means that relative large displacement is needed to reach the peak value from the specified value or decrease to the specified value from the peak value and vice versa.

Similarities exist for the characteristics of the compressive force-displacement curves of the specimens with different deflections or the curves for any type of dent with different depths. Therefore, the parameter values for the deflected specimen and any type of dented specimen were averaged respectively. These values are listed in Table 2.

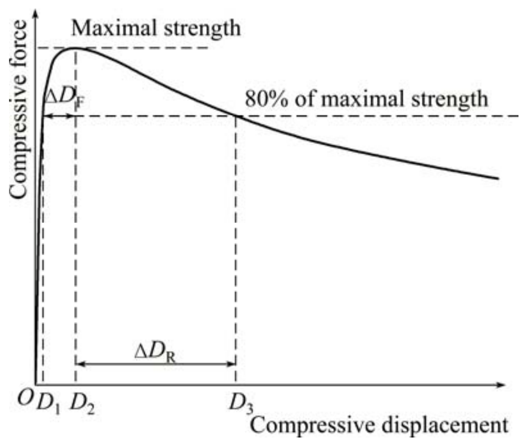

Fig. 10 Compressive force−displacement curve under typical compression condition

Table 2 Parameters comparison of compressive force-displacement curves for intact, deflected, and combined dent and deflected specimens

Type	D_1/mm	D_2/mm	D_3/mm	ΔD_F/mm	ΔD_R/mm
Intact	0.15	0.195	0.4	0.05	0.21
Deflection only	0.32	2.28	5.85	1.96	3.57
Spherical dent and deflection	0.33	1.20	5.19	0.87	3.99
Conical dent and deflection	0.42	1.66	7.43	1.24	5.77
U-shape dent and deflection	0.29	0.79	3.40	0.50	2.61
V-shape dent and deflection	0.28	0.65	2.86	0.37	2.21
Elliptical dent and deflection	0.32	0.81	3.61	0.49	2.80

Compared with the intact specimen, the specimen with only deflection has obviously larger value of D_2, indicating that it delays the maximal strength significantly, whereas, the specimens with combined dent and deflection can weaken this trend, but it still lags behind the intact specimen. For the parameter ΔD_F, a relative small and large displacement was observed for the intact specimen and the deflected specimen respectively, which means that the curve for the intact specimen has a very steep slope at this given range while the deflected specimen has a gentle slope. For the deflected and dented specimen, the displacement duration was shortened and the slope of the curve from D_1 to D_2 becomes a little stiffer, but it still has longer displacement duration than the intact specimen. The comparison of ΔD_R shows that the attenuation speed from the ultimate strength to 80% of the ultimate strength obviously becomes slowly for the deflected specimen than for the intact specimen. Different from the parameters of D_2 and ΔD_F, the five types of dents showed different characteristics in changing the value of ΔD_R. The spherical dent and the conical dent can even weaken this attenuation speed, while the U-shape, V-shape, and elliptical dents can accelerate this attenuation compared with the deflected specimen, but they are still slower than the intact specimen.

4 Discussion and future work

Most of the former studies were on the ultimate strength of dented steel plates commonly used in the ships [9,10,15−17], whereas, few studies and very limited experimental data are available on the ultimate strength of dented aluminum alloy plate [20]. In this study, drop-weight impact tests were conducted on the intact specimen to generate dents on the specimen and then the compression tests were performed on the dented plate to investigate the residual ultimate strength affected by different types of dents.

Compression tests show that the ultimate strength of the dented plate is obviously lower than that of the intact plate. This reduction is mainly due to the plate global deflection caused by the impacts instead of the dents themselves. This finding is consistent with the studies of PAIK et al [9,10] and LUIS et al [11] for steel plates. In the study of GUIJT et al [20], compression tests were conducted on the stiffened 2024-T3 aluminum alloy with or without dents and the results showed that the dents had no substantial effect on the structural stability as well, but the global deflection of the plate was not mentioned.

The ultimate strength characteristics varied for different types of dents. The results show that the ultimate compressive strengths can be increased by the U-shape, V-shape, and elliptical dents along longitudinal direction. The conical dent can decrease the ultimate strength of the plate due to the sharp transition and obvious stress concentration. For the spherical dent, the ultimate strength of the plate decreased at very beginning and then increased with the dent depth. This finding was advocated by LANG and KWON [21] who conducted numerically simulation on the compressive failure load of the 2024-T3 aluminum alloy with spherical dents. However, PAIK et al [9] showed that the influence of the spherical dent on the plate ultimate compressive strength is similar to that of conical dent, both of which decrease the ultimate strength with increasing the dent diameter and depth. This is because in the study of PAIK et al [9] the residual ultimate strength was not considered in simulation for both the spherical and conical dents although the stress distributions were probably different due to the discrepancies in local dent shapes. The simulation probably cannot reflect the response variations of the actual plate with different local dents.

There are a few limitations and delimitations to this study, requiring for further studies. First, the conclusion that the plate global deflection governs the collapse behavior of the plate rather than the local denting-induced behavior is based on the compression condition merely. Next step, it is necessary to investigate the ultimate strength behavior of the dented plated under other conditions (i.e. extension, shear). Another limitation is that only one size configuration was set for the five types of dents and the plate, therefore, numerous finite element analyses will be further conducted to analyze the effect of ultimate strength by dent size, orientation, and plate size (length, width, and thickness) under compression and other conditions. In addition, the ultimate strength characteristics of the dented aluminum alloy plate with stiffeners needed to be further represented besides only the plate.

5 Conclusions

1) The relationships between the impact energies and the parameters regarding sizes/shapes of different types of dents for 2024-T3 aluminum alloy plate were obtained.

2) The ultimate compressive strength of the plate is not affected significantly by only the dent, whereas the plate global deflection governs the primary characteristics of the ultimate strength reduction. The ultimate strength of the plate can be debased badly even subjected to a small global deflection.

3) The ultimate compressive strength of the plate was first slightly decreased and then was increased by the spherical dent with increasing the dent depth. The conical shape dent can accelerate to decrease the ultimate strength of the plate. In addition, the U-shape, V-shape, and elliptical dents can stiffen the plate compressive strength with increase in dent depth. However, for all the types of dents, when obvious cracks or holes were observed (critical condition), they will weaken the increment of the ultimate strength or aggravate the decrease tendency.

4) The sharp “collapse” behavior comes out for the intact specimen during compression, while this behavior was not found for the specimen with only deflection or with combined dent and deflection.

5) Although the ultimate strength of the plate can be obviously decreased by the deflection or the combination of the defection and dent, the strength attenuation speed of dented specimen is slower than intact specimen once the corresponding maximal quantity of the strength is reached.

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轴向压缩载荷下凹坑对 2024-T3 铝合金板剩余强度的影响

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摘 要：使用 5 种冲击头对 2024-T3 铝合金板进行多次冲击试验，然后通过对冲击后的铝合金板进行轴向压缩试验研究凹坑对铝合金板剩余强度的影响。研究结果表明，随着凹坑深度的增加，5 种类型的凹坑以不同的变化规律影响铝合金板的极限强度。然而，相对于冲击过程中产生的平板的整体弯曲变形对极限强度的影响，凹坑本身的影响并不显著。通过对试验数据进行分析，得到冲击能量系数和凹坑深度系数以及极限强度衰减率和凹坑深度系数的方程。

关键词：铝合金板；冲击头；凹坑；剩余极限强度；压缩

(Edited by Hua YANG)