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A METHOD FOR REDUCING THE LENGTH DIFFERENCE OF VICKERS INDENTATION DIAGONAL

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Abstract

This paper aims to analyse the reason for the relatively large length difference of the diagonal of Vickers indentation on the tested material with mechanical anisotropy and propose a feasible method to reduce it. The Vickers hardness test results of the tested material with mechanical anisotropy have shown that the length difference of the diagonal of Vickers indentation on the tested material with mechanical anisotropy would be more than 5% very likely, which is against the test requirement of the related test standard and would affect the test accuracy and effectiveness of the Vickers hardness test. The finite element simulation results of the Vickers hardness test of the tested material with mechanical anisotropy have also shown that the anisotropy of mechanical properties of tested material would affect the length recovery of the diagonal of Vickers indentation on the surface of tested material, thereby affecting the difference of the diagonal length of Vickers indentation. This paper has proposed a method to decrease of diagonal length difference of Vickers indentation through rotating the indenter or the tested material properly and conducting a multiple Vickers hardness test, thereby improving the accuracy and effectiveness of the Vickers hardness test according to the related test standards.

Keywords: Vickers indentation, diagonal length, anisotropic material, indenting direction, test accuracy.

1. Introduction

It is well known that hardness is an important mechanical property of a material, which is its ability to resist the hard object pressing into its surface locally [1, 2]. The hardness of material could be affected by the material type, hardening treatment, temperature, *etc.* [3–5].

Up to now, many test methods have been proposed to test the material hardness, but the indentation method is the frequently-used hardness test method for most materials. The principle of the indentation method for hardness test is to press an hard indenter with a fixed shape under a certain load into tested material surface and then define the hardness according to the magnitude of local plastic deformation on the tested material surface [6, 7]. So far, the common

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indentation method for hardness test have been the Brinell hardness test, Rockwell hardness test, Vickers hardness test, *etc.* [8–10]. Among them, the Vickers hardness test is the most widely used indentation method because it has a wide measurement range and can be applied to almost all materials. The Vickers hardness value is equal to the test force divided by the surface area of indentation on the tested material, which could be expressed by the following equation [11, 12]:

$$HV = \frac{F_{\mathrm{kgf}}}{d^2/\left(2\sin\frac{\alpha}{2}\right)} \approx 0.1891 \times \frac{F}{d^2}, \tag{1}$$

where the HV is the Vickers hardness value of the tested material; the F_{kgf} is the test force in kilogram-force (kgf); the d is the arithmetic mean of the two diagonal lengths (d_1 and d_2) of indentation on the tested material (just as shown in Fig. 1) (mm); the α is the angle between opposite faces at the vertex of the pyramidal indenter, which is fixed at 136°; the F is the test force in newtons (N). Among them, the F is the artificially preset parameter; the d is the mean of d_1 and d_2, and the d_1 and d_2 would be measured through the optical microscope or scanning electron microscope.

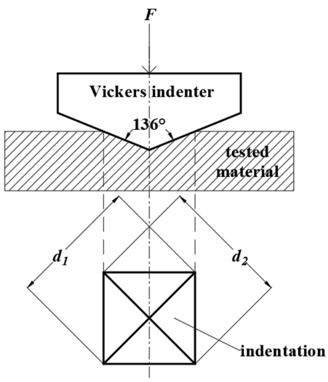

Fig. 1. Principle of the Vickers hardness test.

During the Vickers hardness test, without consideration of measurement error and tested material defects, the two diagonal lengths (d_1 and d_2) of Vickers indentation on the tested material should theoretically be almost the same, which is also the precondition of using (1). According to the related test standards for Vickers hardness, half of one diagonal should not be more than 5% longer than that of half of the other diagonal, otherwise this special situation would not meet the requirement of the related test standards [11, 12].

It is well known that the mechanical performance (just like the yield strength, tensile strength, tensile strain, hardness, *etc.*) in different directions of the material with mechanical isotropy would be basically the same [13, 14]; and the mechanical performance (just like yield strength, tensile strength, tensile strain, hardness, *etc.*) in different directions of the material with mechanical anisotropy would be different to a greater or lesser degree, which can be related to the different microstructure or internal stress of material in different directions [15, 16]. Therefore, under normal conditions, for the Vickers hardness test, the two diagonal lengths of Vickers indentation on the material with mechanical isotropy would be basically the same, and the two diagonal lengths of Vickers indentation on the material with mechanical anisotropy would be different to a greater or lesser degree. Therefore, even without considering the measurement error and tested material defects, the diagonal length difference of the Vickers indentation on a tested material with mechanical anisotropy would be very likely more than 5%, which is against the requirement of the related test standards. However, according to the related test standards for Vickers hardness, if this special situation occurred, the only thing the tester or researchers could do is to indicate it in the test report, but this could cause controversy about the accuracy and effectiveness of Vickers hardness test results. Up to now, this issue has not still received enough attention.

In addition, as shown in Fig. 2, due to the indenter shape of the Brinell indenter (spherical) and Rockwell indenter (conical or spherical), their indentations are always circularly symmetric along the central axis; the shape of the Vickers indenter is right pyramid, and its indentation would be rotationally symmetric along the central axis (the minimum rotation angle is 90°) [17–19]. Therefore, there would be an inevitable angle between the diagonal of Vickers indentation and the placement direction of tested material, which would generally not affect the normal Vickers hardness test and not need to be considered. However, when the tested material is mechanically anisotropic, the angle between the diagonal of Vickers indentation and the placement direction of the tested material can affect the diagonal length of Vickers indentation and thereby the Vickers hardness test results, because plastic deformation in different areas of Vickers indentation can be different due to the different Vickers indenter direction (i.e. the Vickers indentation orientation). But so far, few researches have focused on this topic.

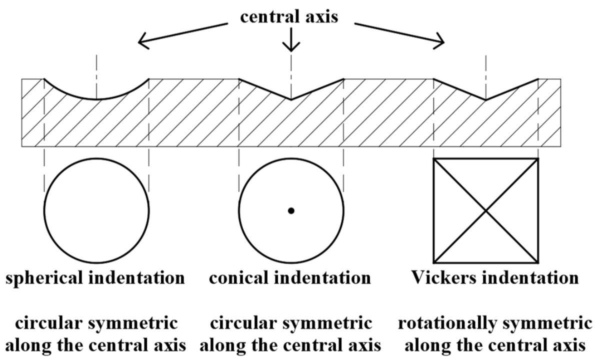

Fig. 2. Symmetry of the indentation shape.

In view of this, this paper presents conducting the Vickers hardness test of material with mechanical anisotropy; researches the effect of material mechanical anisotropy on the diagonal length of Vickers indentation; investigates the relationship between the Vickers indenter direction and the local plastic deformation of Vickers indentation as well as proposes a feasible method to reduce the length difference of the diagonal of Vickers indentation of the material with mechanical anisotropy. The paper will be a helpful reference for the improvement of accuracy of the Vickers hardness test of the material with mechanical anisotropy.

2. Materials and Methods

2.1. Preparation of material with mechanical anisotropy

A pure aluminium sheet, which had been manufactured by vacuum smelting and investment casting, was chosen as the experimental material, and its chemical composition is shown in Table 1. The original thickness of the pure aluminium sheet was 3 mm, and it was next thinned with a cold rolling mill, and the rolling reduction would be 20%, 40%, 60% and 80%, respectively.

After proper cleaning and polishing, the rolled pure aluminium sheet with different thickness was annealed using a vacuum heating furnace at 200°C for 360 min under a high vacuum environment (0.5 Pa–5 Pa) to remove the residual stress.

Table 1. Chemical composition of pure aluminium (wt%).

Elements	Si	Mn	Fe	P	Zn	V	Ti	Al
pure aluminium	0.045	0.003	0.323	0.003	0.001	0.015	0.001	balance

According to the ISO 6892-1:2019 standard, the tensile properties of a rolled sheet with different material orientation would be obtained by a standard tensile test, and the geometrical dimensions of the tensile sample are shown in Fig. 3 [20]. The tensile test was conducted using a universal testing machine at a tensile speed of 2 mm/min at room temperature. As shown in Fig. 4, the sampling directions for the tensile sample on the rolled sheet were the *rolling direction* (RD), *transverse direction* (TD) and 45° *oblique direction* (OD).

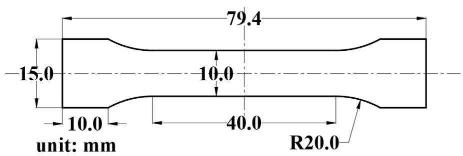

Fig. 3. Geometrical dimensions of a tensile sample.

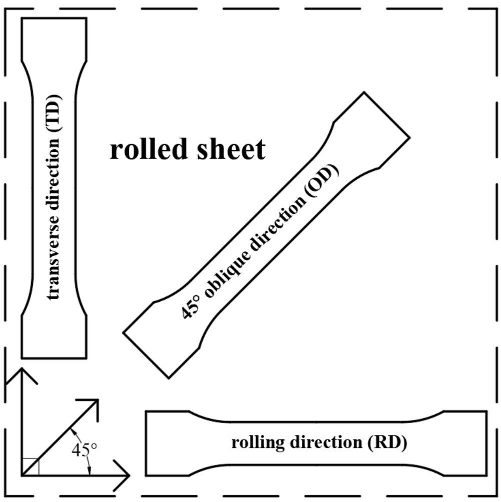

Fig. 4. Sampling direction of the tensile sample on the rolled sheet.

According to the results of the previous research, the degree of mechanical anisotropy of the material can be characterized by the value of *in-plane anisotropy* (hereinafter referred to as "IPA"), and the larger is the value of IPA, the larger will be the in-plane anisotropy of the rolled sheet [21,22]. Thus, the IPA of the rolled sheet can be expressed by the following equation [23,24]:

$$\mathrm{IPA} = \frac{2X_{\max} - X_{\mathrm{mid}} - X_{\min}}{2X_{\max}} \times 100\%, \tag{2}$$

where the IPA is the in-plane anisotropy index of tensile property (yield strength, or tensile strength or tensile strain) of the rolled sheet; the $X_{\max}$, X_{mid} and $X_{\min}$ are the maximum, median and minimum of tensile property (yield strength (MPa), or tensile strength (MPa) or tensile strain) of the rolled sheet in the three sampling directions (*rolling direction* (RD), *transverse direction* (TD) and 45° *oblique direction* (OD)), respectively.

2.2. Vickers hardness measurement

According to the ISO 6507-1:2018 standard, the Vickers hardness test of a rolled sheet with different thickness should be conducted at room temperature [14]. During the Vickers hardness test an indenter is used made of diamond, whose polished surface has no defects. The shape of the Vickers indenter is right pyramid, and the angle between opposite faces at the vertex of the pyramidal indenter is 136°. During the Vickers hardness test, the axis of Vickers indenter was perpendicular to the tested surface of the rolled pure aluminium sheet. The test force, holding time and indenter interval of the Vickers hardness test were 1kgf (9.807N), 10s and 1 mm, respectively.

The indenting direction of the Vickers indenter on the rolled sheets with different thickness is shown in Fig. 5. As can be seen, the rotation angle between the diagonal CD of the Vickers indenter and the *rolling direction* (RD) of the rolled sheets with different thickness was set as 0°, 15°, 30° and 45°, respectively.

After the Vickers hardness test of rolled sheets with different thickness, the Vickers indentation on the rolled sheet was observed with a scanning electron microscope, and the diagonal length of indentation and outline of the indentation edge were measured by the 3D image system of the microscope.

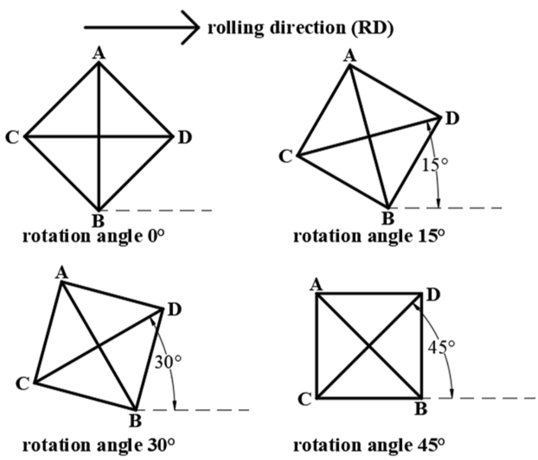

Fig. 5. Indenting direction (rotation angle) of the Vickers indenter on the rolled sheet.

2.3. Finite Element Method simulation of the indentation process

Using the finite element method, the indentation process of Vickers indenter with different indenting direction on the rolled sheets with different thickness was simulated with a commercial finite element program, and then the local stress and geometrical dimension of Vickers indentation was analysed.

The finite element model shape of the Vickers indenter was right pyramid, and the angle between opposite faces at the vertex of the pyramidal indenter was 136°, and the height of the Vickers indenter is set as 0.4 mm. The finite element model shape of the rolled sheet was cylindrical, of which both radius and height were 0.3 mm. The indenter and rolled sheet were set as rigid body (mesh element type: R3D4) and deformable body (mesh element type: C3D8R), respectively. The mesh element number of indenter and the rolled sheet were 20000 and 300000, respectively. The analysis mode and loading method were static analysis and concentrated force loading, respectively. The contact condition and contact property between the indenter and the rolled sheet were set as surface-surface contact and ideal zero friction, respectively. The mechanical parameters of the elasto-plastic model (the relation of stress-strain) of the rolled sheets with different thickness was set according to the tensile test results. The load method of the indenter was set according to the Vickers hardness test experiment parameters.

3. Results and discussion

Figure 6 and Table 2 show the tensile curves and tensile properties of the rolled sheet with different thickness in the three sampling directions, respectively. It can be seen that, as the rolling reduction increased (*i.e.* the sheet thickness decreased), the strength performance index (yield strength and tensile strength) and tensile strain of the rolled sheet in the three sampling directions (*rolling direction* (RD), *transverse direction* (TD) and 45° *oblique direction* (OD)) always increased

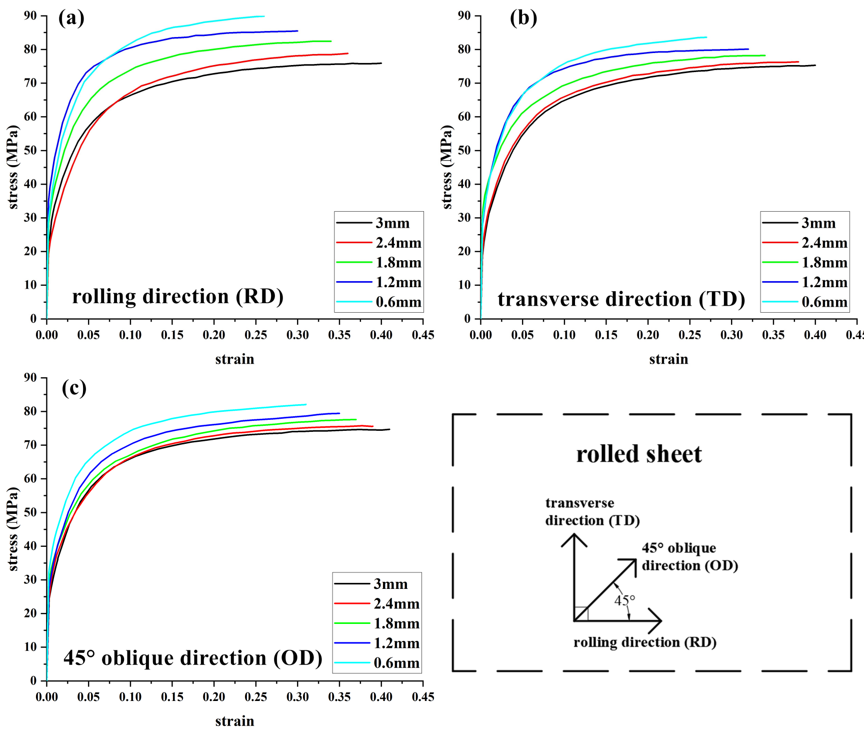

Fig. 6. Tensile curves of rolled sheets with different thickness in the three sampling directions: (a) *rolling direction* (RD), (b) *transverse direction* (TD), (c) 45° *oblique direction* (OD).

Table 2. Tensile properties of rolled sheets with different thickness in the three sampling directions.

Sampling direction	**Rolled sheet thickness (mm)**	**Yield strength (MPa)**	**Tensile strength (MPa)**	**Tensile strain**
Rolling direction (RD)	3	20.1	75.9	0.4
	2.4	23.4	78.8	0.36
	1.8	24.7	82.4	0.34
	1.2	26.7	85.5	0.30
	0.6	28.9	89.9	0.26
Transverse direction (TD)	3	19.8	75.3	0.4
	2.4	22.7	76.3	0.38
	1.8	23.7	78.2	0.34
	1.2	25.6	80.1	0.32
	0.6	27.4	83.6	0.27
45° oblique direction (OD)	3	19.7	74.7	0.41
	2.4	22.5	75.6	0.39
	1.8	23.1	77.6	0.37
	1.2	24.3	79.4	0.35
	0.6	25.7	82.1	0.31

and decreased, respectively. Moreover, for the rolled sheets with the same thickness, the strength performance index (yield strength and tensile strength) in the *rolling direction* (RD) was the largest and the tensile strain in the *rolling direction* (RD) was the smallest.

Figure 7 shows the *in-plane anisotropy* (IPA) of rolled sheets with different thickness. It can be seen that all the IPA of yield strength, tensile strength and tensile strain of the original sheet with the thickness of 3 mm was small. However, as the rolling reduction increased (i.e., the sheet thickness decreased), all the IPA of yield strength, tensile strength and tensile strain of rolled sheet obviously increased.

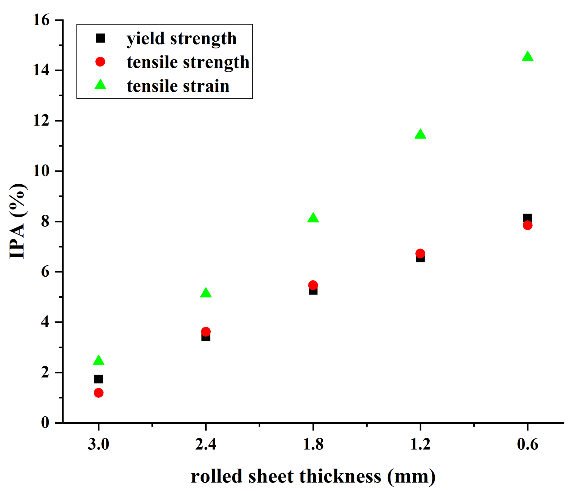

Fig. 7. In-plane anisotropy (IPA) of rolled sheets with different thickness.

Figure 8 shows the indentation with a different indenting direction (rotation angle) on the original sheet with the thickness of 3 mm. It can be seen that, no matter what the indenting direction was, the indentation on the original sheet with the thickness of 3 mm would be basically always in the shape of a square.

Figure 9 shows the outline of indentation edge on the rolled sheet with the thickness of 3 mm with a different indenting direction (rotation angle). It can be seen that, no matter what the rotation angle of indenter (indentation direction) was, the two diagonal (line AB and line CD) length of indentation were equal basically. Moreover, as shown in Fig. 9(d), the two outlines (line AOB and COD) of indentation edge with the indenting direction (rotation angle) of 45°were almost coincident.

Figure 10 shows the indentation with a different indenting direction (rotation angle) on the rolled sheet with the thickness of 0.6 mm. As shown in Fig. 10(a), when the rotation angle of indentation is 0°, the indentation was basically in the shape of a diamond. However, as the rotation angle of indentation increased, the indentation shape would gradually change from diamond to square. When the rotation angle of indentation was 45°, the indentation shape would basically be the shape of a square.

Figure 11 shows the outline of indentation edge on the rolled sheet with the thickness of 0.6 mm with a different indenting direction (rotation angle). It can be seen that, as shown in Fig. 11(a), there was an obvious difference in length between the indentation diagonals (line AB and CD). However, as the rotation angle of indentation increased, the length difference between the indentation diagonals (line AOB and COD) gradually decreased. Moreover, as shown Fig. 11(d), the two outlines (line AOB and COD) of the indentation edge with the indenting direction (rotation angle) of 45° are almost coincident.

Table 3 shows the diagonal length of indentation with a different indenting direction (rotation angle) on the rolled sheets with different thickness. It can be seen that on the rolled sheet with the same thickness, as the rotation angle of the indenter (indentation direction) increased, the difference rate between the two diagonal lengths (d_1 and d_2) of indentation gradually decreases. Moreover, when the indenting direction (rotation angle) on the rolled sheet is 45°, no matter what the rolled sheet thickness was, the difference rate between the two diagonal lengths (d_1 and d_2) of indentation would be always less than 1%.

As mentioned above, according to the related test standards for Vickers hardness, half of one indentation diagonal should not be more than 5% longer than that of half of the other indentation diagonal, otherwise this special situation should be indicated in the test report [14, 15]. However, according to the related experimental results (just as shown in Fig. 10, Fig. 11 and Table 3) of this paper, if the rolling reduction of rolled sheet was large enough (*i.e.* the IPA of rolled sheet was large enough), especially if when the IPA of tested material could not be learned in advance, the length difference rate between half of the diagonals of indentation would exceed 5% very easily, and this situation would not meet the related test standards for Vickers hardness. Nevertheless, the length difference rate between the two indentation diagonals would be small (less than 5%) even on the material with a large IPA (just as shown in Fig. 11, Fig. 11 and Table 3) as long as the indenting direction was rotated properly, and this situation would meet the related test standards for Vickers hardness.

The experimental above results show that the indenting direction of the Vickers indenter on the material with a large IPA could determine if its Vickers hardness test would meet the related test standards, which could be related to the degree of deformation recovery of the indentation surface along the edge of Vickers indentation after unloading.

During the Vickers hardness test, when the test force was unloaded and the Vickers indenter was removed from the tested material surface, the deformation recovery of the indentation surface

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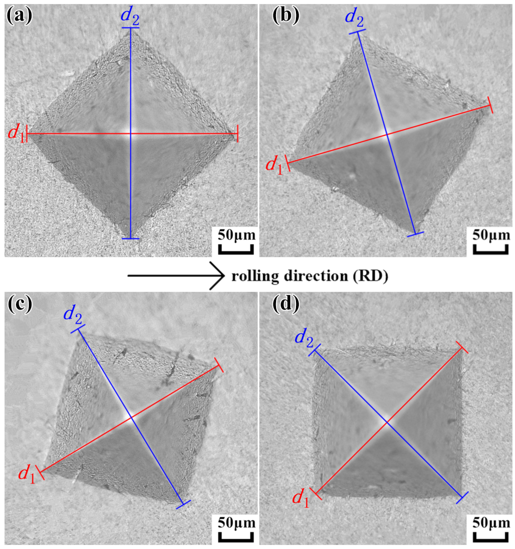

Fig. 8. Indentation with a different indenting direction (rotation angle) on the original sheet with the thickness of 3 mm: (a) 0°, (b) 15°, (c) 30°, (d) 45°.

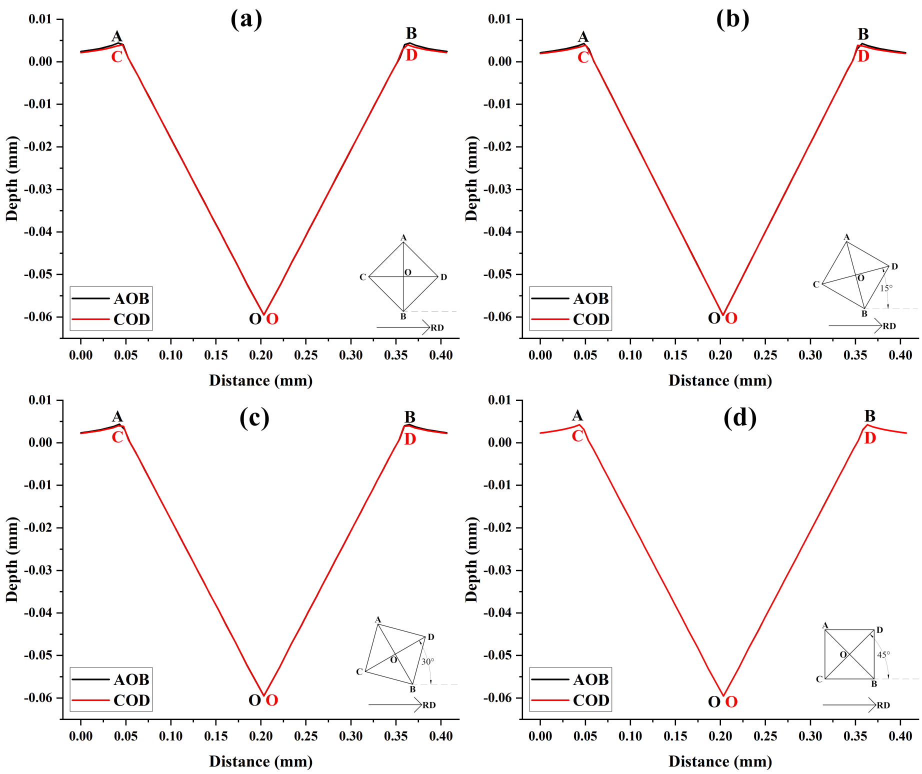

Fig. 9. Outline of indentation edge on the rolled sheet with the thickness of 3 mm with a different indenting direction (rotation angle): (a) 0°, (b) 15°, (c) 30°, (d) 45°.

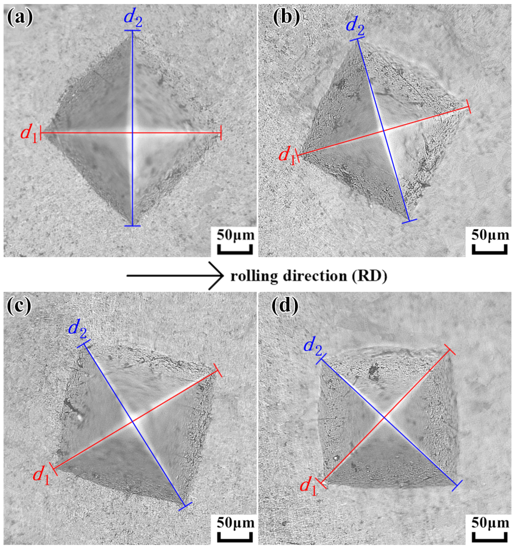

Fig. 10. Indentation with a different indenting direction (rotation angle) on the rolled sheet with the thickness of 0.6 mm: (a) 0°, (b) 15°, (c) 30°, (d) 45°.

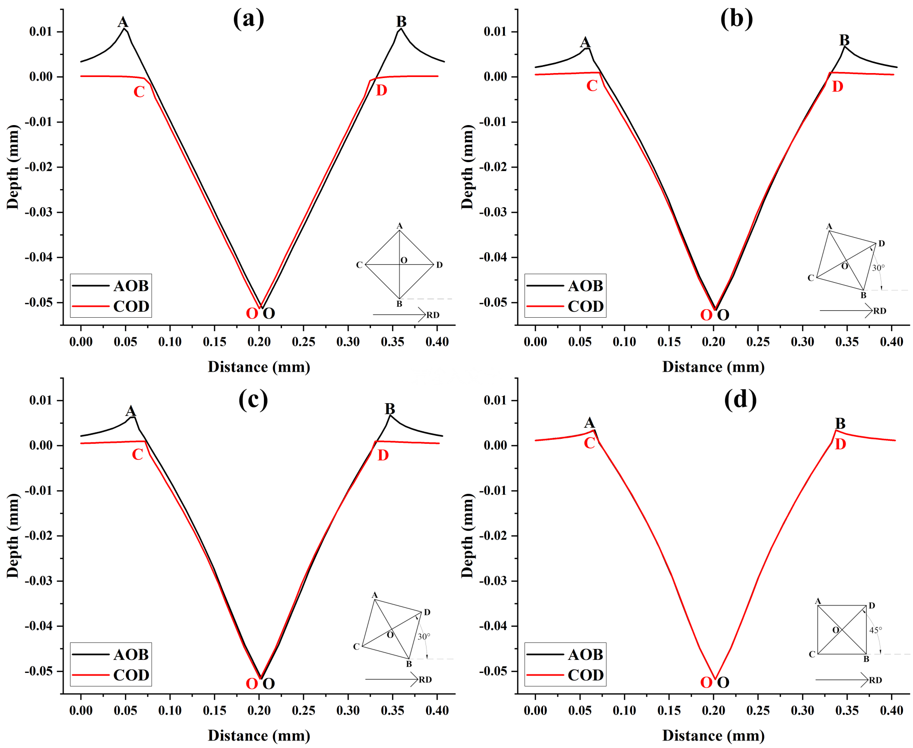

Fig. 11. Outline of the indentation edge on the rolled sheet with the thickness of 0.6 mm with a different indenting direction (rotation angle): (a) 0°, (b) 15°, (c) 30°, (d) 45°.

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Table 3. Diagonal length of indentation with a different indenting direction (rotation angle) on the rolled sheets with different thickness.

Rolled sheet thickness (mm)	Rotation angle (°)	d_1 (mm)	d_2 (mm)	$\frac{\lvert d_2 - d_1 \rvert}{d_1} \times 100\%$
3	0	0.316	0.324	2.53
	15	0.316	0.323	2.17
	30	0.317	0.322	1.57
	45	0.319	0.321	0.62
2.4	0	0.301	0.312	3.65
	15	0.302	0.309	2.31
	30	0.301	0.307	1.99
	45	0.301	0.303	0.66
1.8	0	0.289	0.314	8.65
	15	0.282	0.298	5.67
	30	0.293	0.303	3.41
	45	0.299	0.301	0.67
1.2	0	0.264	0.303	14.77
	15	0.257	0.287	11.67
	30	0.274	0.289	5.47
	45	0.278	0.279	0.36
0.6	0	0.253	0.288	13.83
	15	0.247	0.274	10.93
	30	0.258	0.275	6.59
	45	0.271	0.273	0.74

occurred. The degree of deformation recovery of the indentation surface affected the indentation shape and the diagonal length, thereby deciding whether the Vickers hardness test would meet the related test standards (i.e., whether the diagonal length difference of the Vickers indentation on the tested material was more than 5%). The deformation recovery of the indentation surface along the vertical direction would be related to the mechanical properties of tested material along the vertical direction, and the deformation recovery of indentation surface along the horizontal direction would be related to the mechanical properties of tested material along the horizontal direction. The degree of deformation recovery of indentation surface would be determined by the mechanical properties of tested material, which, in turn, could be characterized by the stress state of the indentation surface.

Figure 12 shows the stress distribution contour of the indentation surface on the rolled sheet with the thickness of 3 mm with a different indenting direction (rotation angle) after unloading. It can be seen that, no matter what the indenting direction (rotation angle) is, both stress distribution and indentation shape were almost same.

Figure 13 shows the stress curve along the indentation edge on the rolled sheet with the thickness of 3 mm with a different indenting direction (rotation angle) after unloading. It can be seen that the stress distribution along the two indentation edges was similar and would gradually become coincident as the rotation angle of indentation increased. Furthermore, as shown in Fig. 13(d), when the rotation angle of indentation is 45°, the stress distribution curves along both indentation edges were completely coincident.

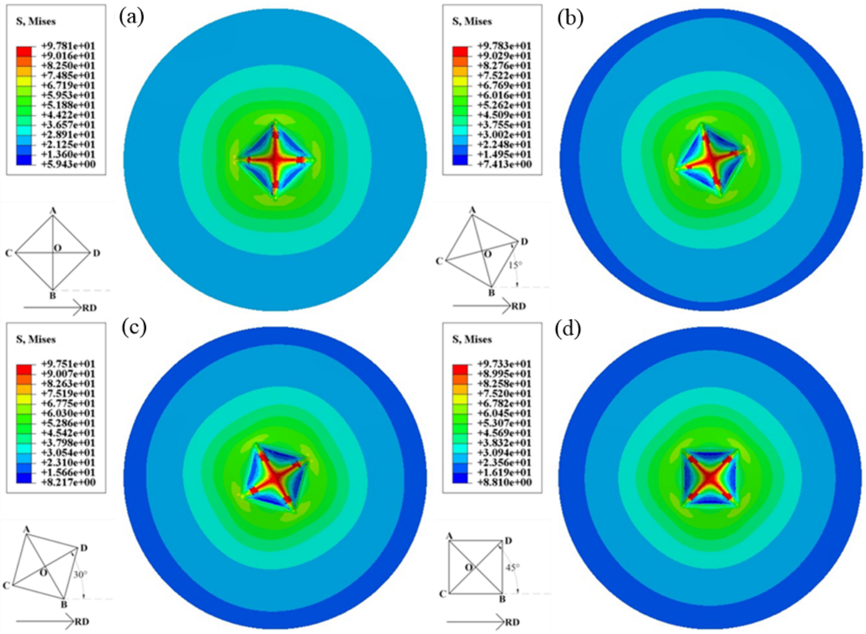

Fig. 12. Stress distribution contour of the indentation surface on the rolled sheet with the thickness of 3 mm with a different indenting direction (rotation angle) after unloading: (a) 0°, (b) 15°, (c) 30°, (d) 45°.

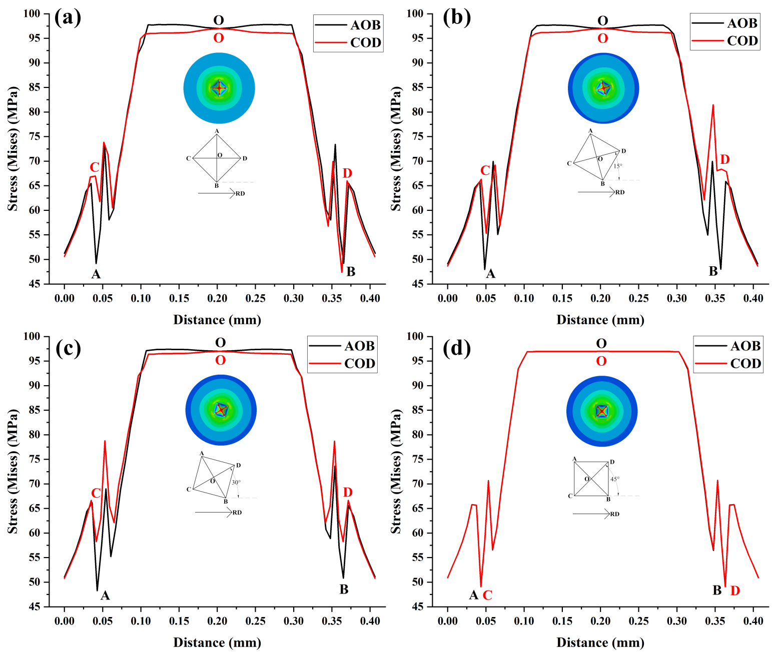

Fig. 13. Stress curve along the indentation edge on the rolled sheet with the thickness of 3 mm with a different indenting direction (rotation angle) after unloading: (a) 0°, (b) 15°, (c) 30°, (d) 45°.

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Figure 14 shows the stress distribution contour of indentation surface on the rolled sheet with the thickness of 0.6 mm with a different indenting direction (rotation angle) after unloading. As can be seen in Fig. 14(a), the indentation was basically diamond-shaped and the stress distribution along the indentation edge AOB was obviously different from that along the indentation edge COD. However, as the rotation angle of indentation increased, the indentation shape gradually changed from diamond to square and the difference of stress distribution along between the indentation edges AOB and COD gradually decreased. As shown in Fig. 14(d), when the rotation angle of indentation was 45°, the indentation shape was basically square-shaped and the stress distribution along the two indentation edges (AOB and COD) was basically the same.

Figure 15 shows the stress curve along the indentation edge on the rolled sheet with the thickness of 3 mm with a different indenting direction (rotation angle) after unloading. As one can see in Fig. 14(a), the stress distribution curve along the indentation edge AOB was obviously different from that along the indentation edge COD. However, as the rotation angle of indentation increased, the difference of the stress distribution curve between the indentation edges AOB and COD gradually decreased. As shown in Fig. 15(d), when the rotation angle of indentation was 45°, the stress distribution curves along indentation edges was completely coincident.

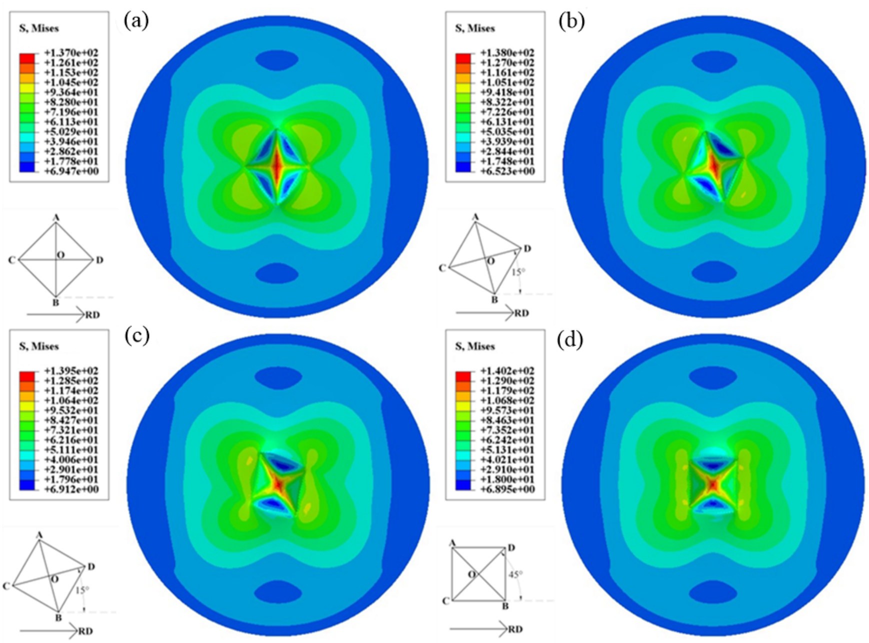

Fig. 14. Stress distribution contour of the indentation surface on the rolled sheet with the thickness of 0.6 mm with a different indenting direction (rotation angle) after unloading: (a) 0°, (b) 15°, (c) 30°, (d) 45°.

Moreover, the further finite element simulation results for this paper have shown that, no matter what the IPA of material is, as the rotation angle of indentation increases, the difference of stress distribution on the indentation surface gradually decreased; when the rotation angle of indentation was 45°, the stress distributions on both indentation edges were basically the same.

The finite element simulation results above have shown that the indentation shape (i.e. the diagonal length) is related to stress distribution along the indentation edge, which can be attributed to the indenting direction (rotation angle) of the Vickers indenter and the IPA of the material.

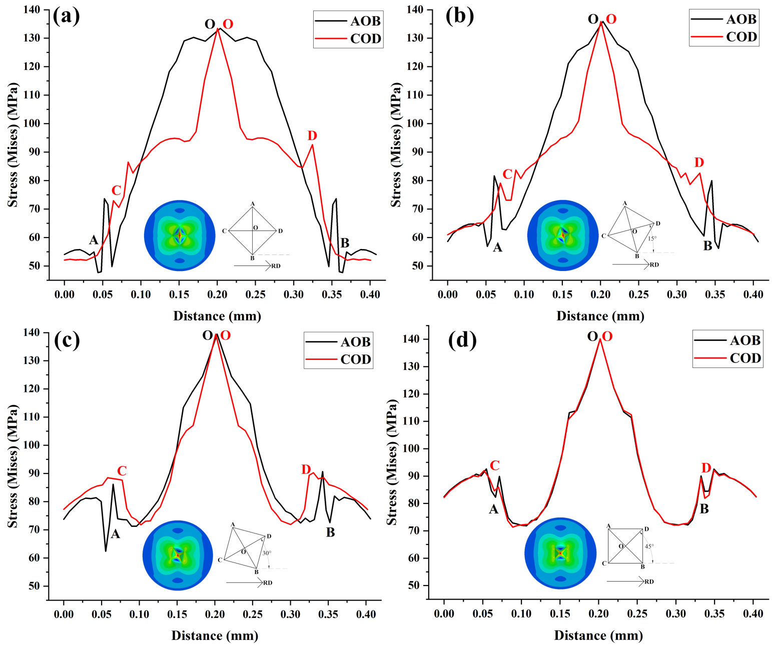

Fig. 15. Stress curve along the indentation edge on the rolled sheet with the thickness of 0.6 mm with a different indenting direction (rotation angle) after unloading: (a) 0°, (b) 15°, (c) 30°, (d) 45°.

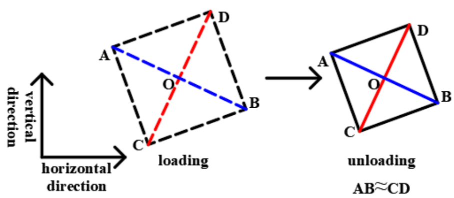

Fig. 16. Deformation recovery of indentation surface on the tested material with mechanical isotropy after unloading.

When the tested material is mechanically isotropic, there is little difference in the mechanical properties between the vertical direction and the horizontal direction of the tested material. No matter what the indenting direction (rotation angle) of the Vickers indenter is, the basically the same stress states of both indentation edges (just as shown in Fig. 12 and Fig. 13) indicate that the deformation recovery of both indentation edges can be basically identical, causing little length difference between the diagonals of indentation (just as shown in Fig. 16).

When the tested material is mechanically anisotropic, there is a difference in the mechanical properties between along the vertical direction and along the horizontal direction of tested material. When the indenting direction (rotation angle) is 0°, one diagonal of indentation would be perpendicular to the horizontal direction of the tested material and the other diagonal of indentation would be parallel to horizontal direction of the tested material. The obviously different stress states of both indentation edges (just as shown in Fig. 14(a) and Fig. 15(a)) indicate that the deformation recovery of both indentation edges are obviously different, causing a large length difference between the diagonals of indentation (just as shown in Fig. 17(a)). When the indenting direction (rotation angle) is between 0° and 45°, both diagonals of indentation would be neither perpendicular

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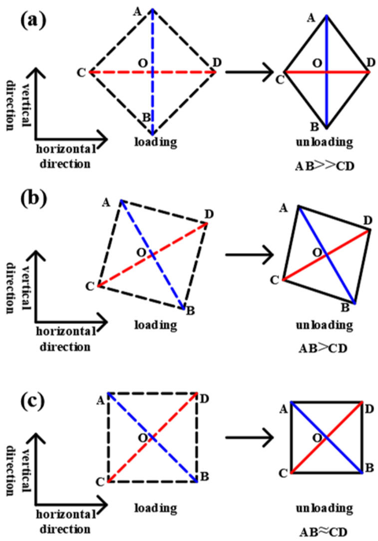

Fig. 17. Deformation recovery of indentation surface on the tested material with mechanical anisotropy after unloading with a different indenting direction (rotation angle): (a) 0°, (b) 30°, (c) 45°.

or parallel to horizontal direction of tested material. The relatively different stress states of both indentation edges (just as shown in Fig. 14(c) and Fig. 15(c)) indicates that the deformation recovery of both indentation edges is relatively different, causing a relatively large length difference between the diagonals of indentation (just as shown in Fig. 17(b)). When the indenting direction (rotation angle) is 45°, the angle between the horizontal direction of tested material and either diagonal of indentation is 45°. The basically same stress states of both indentation edges (just as shown in Fig. 14(d) and Fig. 15(d)) indicate that the deformation recovery of both indentation edges are basically the same, causing little length difference between the diagonals of indentation (just as shown in Fig. 17(c)).

In sum, to avoid the occurrence of a special situation (*i.e.* the diagonal length difference of the Vickers indentation of more than 5%) mentioned in the related test standards for Vickers hardness, this paper would suggest that, when the in-plane anisotropy of the material tested under Vickers hardness measurement could not be learned in advance, the measurements with multiple indenting direction (rotation angle) should be conducted first, preceding the selection of the indenting direction (rotation angle) which would possess the largest diagonal length difference of indentation on the tested material, and then rotating the indenter or the tested material by 45°, and finally conducting the Vickers hardness measurement again. In this state, the diagonal length difference of indentation on the tested material would be the smallest (at least less than 5%), and the special situation (i.e. the half of one diagonal would be more than 5% longer than that of half of the other diagonal of the Vickers indentation on the tested material) would not happen and need not to be indicated in the test report. Of course, the method proposed in this paper would not be mandatory.

Moreover, this paper holds that the in-plane anisotropy and its anisotropic direction of a certain material could be evaluated roughly according to the diagonal length difference of indentation on a given material through the Vickers hardness test. No matter what the indenting direction (rotation angle) is, if the diagonal length difference of indentation on the certain material is small, the given material should be considered as isotropic. If there is a (rotation angle) indenting direction to make the length difference between the diagonals of indentation largest, the given material should be treated as anisotropic, and the direction of the diagonal with the relatively small length could be confirmed to be the cold-working direction of this material.

4. Conclusions

This paper has proposed a method to reduce the length difference of the diagonal of Vickers indentation on the tested material with mechanical anisotropy, thereby improving the accuracy and effectiveness of Vickers hardness test results according to the related test standards. The Vickers hardness test results of the tested material with mechanical anisotropy have shown that the length difference of the diagonal of Vickers indentation on the tested material with mechanical anisotropy would vary with the change of indenting direction of the Vickers indenter. Very likely, it would be larger than 5% and this special situation is against the requirements of the related test standards, thereby affecting the accuracy and effectiveness of the Vickers hardness test. The finite element simulation results of the Vickers hardness test of the tested material with mechanical anisotropy have shown that the diagonal length of Vickers indentation would be related to the deformation recovery of tested material, which would be determined by the anisotropy of mechanical properties of tested material. This paper holds that, for the Vickers hardness test of the tested material with mechanical anisotropy, rotating the indenter or the tested material properly and conducting multiple Vickers hardness tests can lead to achieving the indenting direction along which the diagonal length difference of Vickers indentation is less than 5%, thereby making the test condition meet the requirement of the related test standards.

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