CLAIMS

1. A carbide end mill which includes a plurality of wavy peripheral cutting edges each having alternate crest portions and trough portions, or a plurality of peripheral cutting edges each having a plurality of nicks for breaking chips, wherein, when a certain peripheral cutting edge is considered a reference peripheral cutting edge having reference phases, wherein the distance of the reference phase is an amount corresponding to a value obtained by dividing the pitch of the nicks or waveform of the reference peripheral cutting edge by the number of the cutting edges; and the phase of at least one of the remaining peripheral cutting edges is deviated in the direction of a tool axis from the corresponding reference phase by an amount of 5% or less (excluding 0%) of the pitch.

2. A carbide end mill according to claim 1, the phase of at least one of the remaining peripheral cutting edges is deviated in the direction of the tool axis from the corresponding reference phase by an amount corresponding to 1% to 3% of the pitch.

3. A carbide end mill according to claim 1, wherein the carbide end mill has three or more peripheral cutting edges; at least a pair of peripheral cutting edges of the adjacent peripheral cutting edges have no phase deviation from the

respective reference phases of the reference peripheral cutting edge, wherein, the distance of the reference phase is an amount corresponding to a value obtained by dividing the pitch of the nicks or waveform of the reference peripheral cutting edge by the number of the cutting edges——and the amounts of phase deviation of the remaining peripheral cutting edges from the respective reference phases are unequal with each other.

4. A carbide end mill according to claim 1, wherein each peripheral cutting edge has a plurality of nicks; when one peripheral cutting edge and its nicks are viewed on a cross section skewed at an angle equal to a helix angle of the end mill, opposite ends of each nick are smoothly connected to adjacent portions of the peripheral cutting edge via rounded portions; and the radius of curvature of the tool-end-side round portion of the nick is smaller than that of the tool-shank-side round portion of the nick.

5. A carbide end mill according to claim 4, wherein the bottom end of the groove of each nick is connected with the tool-shank-side round portion via a straight portion or a curve portion which is convexed toward the nick, or connected with the tool-shank-side round portion via a straight portion and a curve portion which is convexed toward the nick.

6. A carbide end mill according to claim 4, wherein, when the tool diameter of the nicked carbide end mill is represented by D, the radius of curvature of the tool-end-side rounded portion of each nick is 0.01D to 0.03D, the radius of curvature of the tool-shank-side rounded portion of each nick is 1.5 to 2 times the radius of curvature of the tool-end-side rounded portion of each nick, and the depth of each nick is 0.01D to 0.05D.

7. A carbide end mill according to any one of claims 1 to 6, wherein, the carbide end mill includes the plurality of peripheral cutting edges, end cutting edges, and gashes each composed of a plurality of gash surfaces; the plurality of gash surfaces include a first gash surface serving as a cutting face of the corresponding end cutting edge, a second gash surface provided on the side toward the rotational center of the tool axis of the end mill, and a third gash surface provided on the peripheral side of the end mill; a first gash angle of 15° to 35° is formed between a crossing portion between the first gash surface and the second gash surface, and a plane perpendicularly intersecting the tool axis; a second gash angle of 40° to 60° is formed between a crossing portion between the first gash surface and the third gash surface, and the plane perpendicularly intersecting the tool axis; and the length of a connection portion between the second gash surface and the third gash surface is not less than 5% the tool diameter as measured

from the tool rotation axis and less than 20% the tool diameter.

8. A carbide end mill according to any one of claims 1 to 6, wherein the end mill is used to cut a workpiece formed of structural steel, structural alloy steel, die steel for cold working, die steel for hot working, stainless steel, titanium alloy, or super-heat-resistant alloy.

9. A carbide end mill according to any one of claims 1 to 6, wherein the wavy peripheral cutting edges are covered with a hard coat.

10. A carbide end mill according to claim 9, wherein the hard coat is composed of an outermost layer and an innermost layer in contact with the surfaces of the peripheral cutting edges, or the hard coat is composed of a composite layer substantially equivalent to a layered structure composed of alternately layered first and second layers, the first layers having the same composition as the innermost layer and the second layers having the same composition as the outermost layer, or a composite layer including the innermost layer and the outermost layer, and one or more intermediate layers interposed therebetween; and the outermost layer is greater in oxidation resistance and wear resistance than the innermost layer.

11. A carbide end mill according to claim 10, wherein the innermost layer of the hard coat is formed of compound selected from one of a nitride, carbonitride, oxynitride, and oxycarbonitride containing Ti and Al as main metallic components, and the outermost layer of the hard coat is formed of compound selected from one of a nitride, carbonitride, oxynitride, or oxycarbonitride containing Ti and Si as main metallic components.

12. A carbide end mill according to claim 10, wherein the innermost layer of the hard coat is formed of a nitride containing one or more metal elements selected from among Al, Cr, Ti, and Si; the intermediate layer is formed of a compound containing one or more metal elements selected from among Al, Cr, Ti, and Si, and one or more elements selected from among N, B, C, and O; and the outermost layer of the hard coat is formed of a compound containing one or more metal elements selected from among Ti and Si, and one or more elements selected from among N, S, C, and B.

13. A carbide end mill according to claim 10, wherein each of the innermost layer and the outermost layer of the coat is formed of a nitrogen-containing TiAl compound which is represented by the formula $Ti_xAl_{1-x}N$, the innermost layer is formed of titanium-rich $Ti_xAl_{1-x}N$ (i.e., $0.5 < x \leq 1$), and the outermost layer is formed of aluminum-rich $Ti_xAl_{1-x}N$ (i.e., $0 \leq x < 0.5$).

14. A carbide end mill according to any one of claims 1 to 6, wherein the end mill is used to cut a workpiece formed of structural steel, structural alloy steel, die steel for cold or hot working, stainless steel, titanium alloy, or super-heat-resistant alloy; and

the carbide end mill includes the plurality of peripheral cutting edges, end cutting edges, and gashes each composed of a plurality of gash surfaces; the plurality of gash surfaces include a first gash surface serving as a cutting face of the corresponding end cutting edge, a second gash surface provided on the side toward the rotational center of the tool axis of the end mill, and a third gash surface provided on the peripheral side of the end mill; a first gash angle of 15° to 35° is formed between a crossing portion between the first gash surface and the second gash surface, and a plane perpendicularly intersecting the tool axis; a second gash angle of 40° to 60° is formed between a crossing portion between the first gash surface and the third gash surface, and the plane perpendicularly intersecting the tool axis; and the length of a connection portion between the second gash surface and the third gash surface is not less than 5% the tool diameter as measured from the tool rotation axis and less than 20% the tool diameter.

15. A carbide end mill according to any one of claims 1 to

6, wherein the carbide end mill includes the plurality of peripheral cutting edges, end cutting edges, and gashes each composed of a plurality of gash surfaces; the plurality of gash surfaces include a first gash surface serving as a cutting face of the corresponding end cutting edge, a second gash surface provided on the side toward the rotational center of the tool axis of the end mill, and a third gash surface provided on the peripheral side of the end mill; a first gash angle of 15° to 35° is formed between a crossing portion between the first gash surface and the second gash surface, and a plane perpendicularly intersecting the tool axis; a second gash angle of 40° to 60° is formed between a crossing portion between the first gash surface and the third gash surface, and the plane perpendicularly intersecting the tool axis; and the length of a connection portion between the second gash surface and the third gash surface is not less than 5% the tool diameter as measured from the tool rotation axis and less than 20% the tool diameter; and

the wavy peripheral cutting edges are covered with a hard coat.

16. A carbide end mill according to claim 15, wherein the hard coat is composed of an outermost layer and an innermost layer which is stacked directly on the surfaces of the peripheral cutting edges, or the hard coat is formed of a composite layer stacked by repeating substantially the same

composition of the outermost layer and the innermost layer, or the hard coat is formed of a composite layer including one or more intermediate layers between the innermost layer and the outermost layer, and the outermost layer is greater in oxidation resistance and in wear resistance than the innermost layer.

17. A carbide end mill according to claim 16, wherein the innermost layer of the hard coat is formed of selecting from a nitride, carbonitride, oxynitride, and oxycarbonitride containing Ti and Al as main metallic components, and the outermost layer of the hard coat is formed of a nitride, carbonitride, oxynitride, or oxycarbonitride containing Ti and Si as main metallic components.

18. A carbide end mill according to claim 16, wherein the innermost layer of the hard coat is formed of a nitride containing one or more metal elements selected from among Al, Cr, Ti, and Si; the intermediate layer is formed of a compound containing one or more metal elements selected from among Al, Cr, Ti, and Si, and one or more elements selected from among N, B, C, and O; and the outermost layer of the hard coat is formed of a compound containing one or more metal elements selected from among Ti and Si, and one or more elements selected from among N, S, C, and B.

19. A carbide end mill according to claim 16, wherein each

of the innermost layer and the outermost layer is formed of a nitrogen-containing TiAl compound which is represented by the formula $Ti_xAl_{1-x}N$, the innermost layer is formed of titanium-rich $Ti_xAl_{1-x}N$ (i.e., $0.5 < x \leq 1$), and the outermost layer is formed of aluminum-rich $Ti_xAl_{1-x}N$ (i.e., $0 \leq x < 0.5$).

20. A carbide end mill according to claim 15, wherein a cutting edge portion formed of carbide is detachably attached to a tool-holding portion.

21. A carbide end mill according to any one of claims 1 to 6, wherein a cutting edge portion formed of carbide is detachably attached to a tool-holding portion.

22. A carbide end mill which includes a plurality of wavy peripheral cutting edges each having alternate crest portions and trough portions, or a plurality of peripheral cutting edges each having a plurality of nicks for breaking chips, wherein the carbide end mill includes the plurality of peripheral cutting edges, end cutting edges, and gashes each composed of a plurality of gash surfaces; the plurality of gash surfaces include a first gash surface serving as a cutting face of the corresponding end cutting edge, a second gash surface provided on the side toward the rotational center of the tool axis of the end mill, and a third gash surface provided on the peripheral side of the end mill; a

first gash angle of 15° to 35° is formed between a crossing portion between the first gash surface and the second gash surface, and a plane perpendicularly intersecting the tool axis; a second gash angle of 40° to 60° is formed between a crossing portion between the first gash surface and the third gash surface, and the plane perpendicularly intersecting the tool axis; and the length of a connection portion between the second gash surface and the third gash surface is not less than 5% the tool diameter as measured from the tool rotation axis and less than 20% the tool diameter.

23. A cutting method characterized by comprising the step of successively performing at least two types of cutting operations selected from longitudinal-feed cutting, lateral-feed cutting, and oblique cutting, by use of a carbide end mill, wherein

the carbide end mill includes a plurality of wavy peripheral cutting edges each having alternate crest portions and trough portions, or a plurality of peripheral cutting edges each having a plurality of nicks for breaking chips, end cutting edges, and gashes each composed of a plurality of gash surfaces;

the peripheral cutting edges are covered by a hard coat;

the plurality of gash surfaces include a first gash surface serving as a cutting face of the corresponding end

cutting edge, a second gash surface provided on the side toward the rotational center of the tool axis of the end mill, and a third gash surface provided on the peripheral side of the end mill;

a first gash angle of 15° to 35° is formed between a crossing portion between the first gash surface and the second gash surface, and a plane perpendicularly intersecting the tool axis;

a second gash angle of 40° to 60° is formed between a crossing portion between the first gash surface and the third gash surface, and the plane perpendicularly intersecting the tool axis;

the length of a connection portion between the second gash surface and the third gash surface is not less than 5% the tool diameter as measured from the tool rotation axis and less than 20% the tool diameter; and

the peripheral cutting edges are formed such that, when a certain peripheral cutting edge is considered a reference peripheral cutting edge having reference phases, wherein the distance of the reference phase is an amount corresponding to a value obtained by dividing the pitch of the nicks or waveform of the reference peripheral cutting edge by the number of the cutting edges, and the phase of at least one of the remaining peripheral cutting edges is deviated in the direction of the tool axis from the corresponding reference phase by an amount of 5% or less (excluding 0%) of the pitch.

CLAIMS

1. A carbide end mill which includes a plurality of wavy peripheral cutting edges each having alternate crest portions and trough portions, or a plurality of peripheral cutting edges each having a plurality of nicks for breaking chips, wherein, when a certain peripheral cutting edge is considered a reference peripheral cutting edge having reference phases, wherein the distance of the reference phase is an amount corresponding to a value obtained by dividing the pitch of the nicks or waveform of the reference peripheral cutting edge by the number of the cutting edges; and the phase of at least one of the remaining peripheral cutting edges is deviated in the direction of a tool axis from the corresponding reference phase by an amount of 5% or less (excluding0%) of the pitch, wherein, the carbide end mill includes the plurality of peripheral cutting edges, end cutting edges, and gashes each composed of a plurality of gash surfaces; the plurality of gash surfaces include a first gash surface serving as a cutting face of the corresponding end cutting edge, a second gash surface provided on the side toward the rotational center of the tool axis of the end mill, and a third gash surface provided on the peripheral side of the end mill; a first gash angle of 15° to 35° is formed between a crossing portion between the first gash surface and the second gash surface, and a plane perpendicularly intersecting the tool axis; a

second gash angle of 40° to 60° is formed between a crossing portion between the first gash surface and the third gash surface, and the plane perpendicularly intersecting the tool axis; and the length of a connection portion between the second gash surface and the third gash surface is not less than 5% the tool diameter as measured from the tool rotation axis and less than 20% the tool diameter.

2. A carbide end mill according to claim 1, the phase of at least one of the remaining peripheral cutting edges is deviated in the direction of the tool axis from the corresponding reference phase by an amount corresponding to 1% to 3% of the pitch.

3. A carbide end mill according to claim 1, wherein the carbide end mill has three or more peripheral cutting edges; at least a pair of peripheral cutting edges of the adjacent peripheral cutting edges have no phase deviation from the respective reference phases of the reference peripheral cutting edge, wherein, the distance of the reference phase is an amount corresponding to a value obtained by dividing the pitch of the nicks or waveform of the reference peripheral cutting edge by the number of the cutting edges---and the amounts of phase deviation of the remaining peripheral cutting edges from the respective reference phases are unequal with each other.

4. A carbide end mill according to claim 1, wherein each peripheral cutting edge has a plurality of nicks; when one peripheral cutting edge and its nicks are viewed on a cross section skewed at an angle equal to a helix angle of the end mill, opposite ends of each nick are smoothly connected to adjacent portions of the peripheral cutting edge via rounded portions; and the radius of curvature of the tool-end-side round portion of the nick is smaller than that of the tool-shank-side round portion of the nick.

5. A carbide end mill according to claim 4, wherein the bottom end of the groove of each nick is connected with the tool-shank-side round portion via a straight portion or a curve portion which is convexed toward the nick, or connected with the tool-shank-side round portion via a straight portion and a curve portion which is convexed toward the nick.

6. A carbide end mill according to claim 4, wherein, when the tool diameter of the nicked carbide end mill is represented by D, the radius of curvature of the tool-end-side rounded portion of each nick is 0.01D to 0.03D, the radius of curvature of the toolshank-side rounded portion of each nick is 1.5 to 2 times the radius of curvature of the tool-end-side rounded portion of each nick, and the depth of each nick is 0.01D to 0.05D.

7. A carbide end mill according to any one of claims 1 to 6, wherein the wavy peripheral cutting edges are covered with a hard coat.

8. A carbide end mill according to any one of claims 1 to 6, wherein a cutting edge portion formed of carbide is detachably attached to a tool-holding portion.

9. A carbide end mill which includes a plurality of wavy peripheral cutting edges each having alternate crest portions and trough portions, or a plurality of peripheral cutting edges each having a plurality of nicks for breaking chips, wherein the carbide end mill includes the plurality of peripheral cutting edges, end cutting edges, and gashes each composed of a plurality of gash surfaces; the plurality of gash surfaces include a first gash surface serving as a cutting face of the corresponding end cutting edge, a second gash surface provided on the side toward the rotational center of the tool axis of the end mill, and a third gash surface provided on the peripheral side of the end mill; a first gash angle of 15° to 35° is formed between a crossing portion between the first gash surface and the second gash surface, and a plane perpendicularly intersecting the tool axis; a second gash angle of 40° to 60° is formed between a crossing portion between the first gash surface and the third gash surface, and the plane perpendicularly intersecting the tool axis; and the length of a connection portion between the

second gash surface and the third gash surface is not less than 5% the tool diameter as measured from the tool rotation axis and less than 20% the tool diameter.