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Yamada et al.

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(54) **METHOD FOR SETTING SHOT-PEENING PROCESS CONDITION**

(75) Inventors: **Takeshi Yamada**, Nagoya (JP); **Akiko Inoue**, Nagoya (JP)

(73) Assignee: **MITSUBISHI HEAVY INDUSTRIES, LTD.**, Tokyo (JP)

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B24C 7/00 (2006.01)
C21D 7/06 (2006.01)

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CPC ***B24C 1/10*** (2013.01); ***B24C 7/0053*** (2013.01); ***B24C 7/0061*** (2013.01); ***C21D 7/06*** (2013.01)

(58) **Field of Classification Search**
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USPC 72/53; 29/90.7; 73/11.02
See application file for complete search history.

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Primary Examiner — Edward Tolan
(74) *Attorney, Agent, or Firm* — Wenderoth, Lind & Ponack, L.L.P.

(57) **ABSTRACT**

A method for setting a shot-peening process condition includes a step of obtaining, for each of a plurality of peening conditions for a first combination as a combination of a shot peening processing apparatus and media, a saturation time based on a saturation curve indicating a change in an arc height value of an Almen strip against a projection time. The method includes a step of determining a first optimum peening condition corresponding to the first combination based on the saturation time.

24 Claims, 19 Drawing Sheets

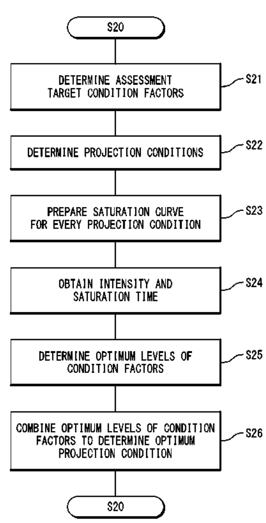

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Fig. 1

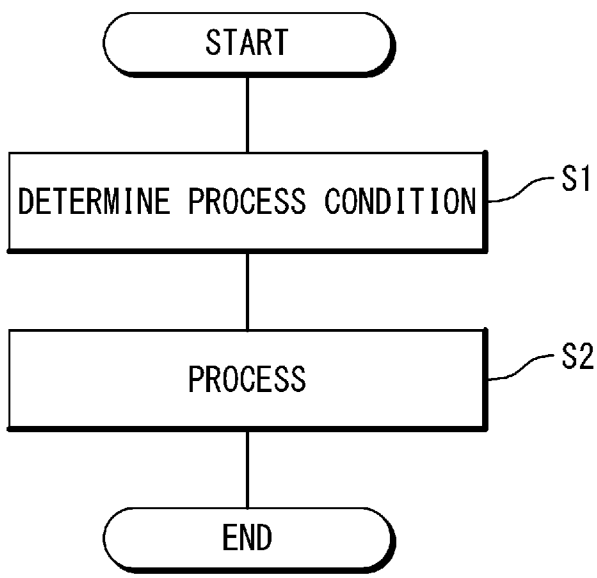


Fig. 2

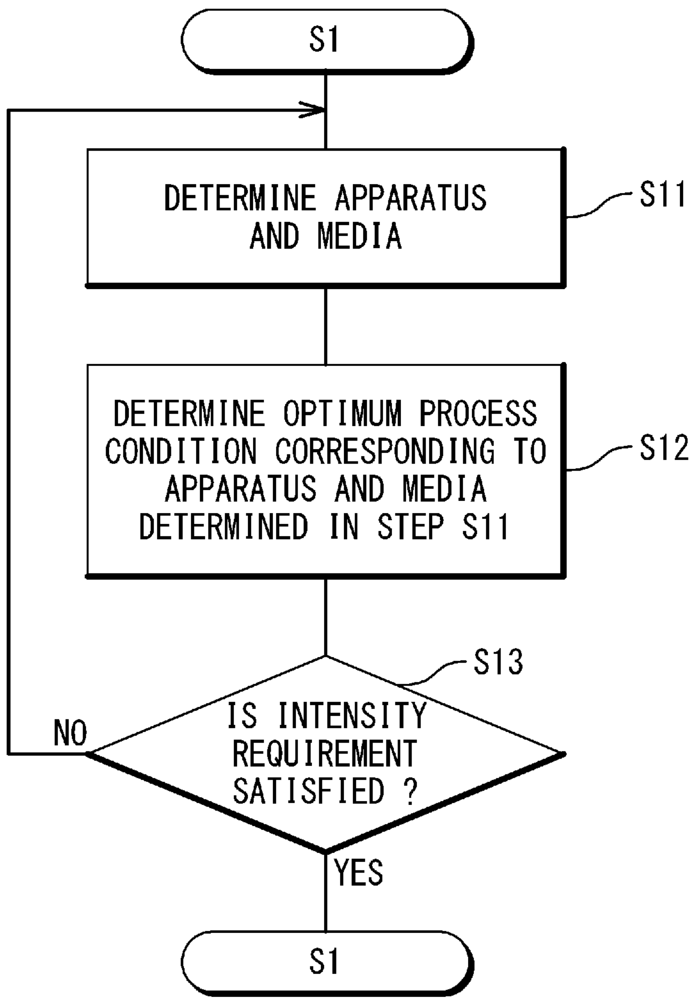

S1
DETERMINE APPARATUS AND MEDIA
S11
DETERMINE OPTIMUM PROCESS CONDITION CORRESPONDING TO APPARATUS AND MEDIA DETERMINED IN STEP S11
S12
IS INTENSITY REQUIREMENT SATISFIED ?
S13
NO
YES
S1

Fig. 3

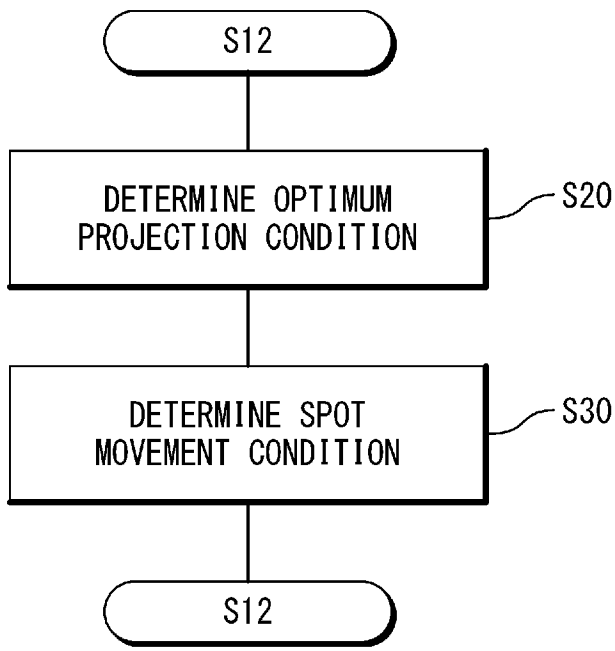

S12
DETERMINE OPTIMUM PROJECTION CONDITION
S20
DETERMINE SPOT MOVEMENT CONDITION
S30
S12

Fig. 4

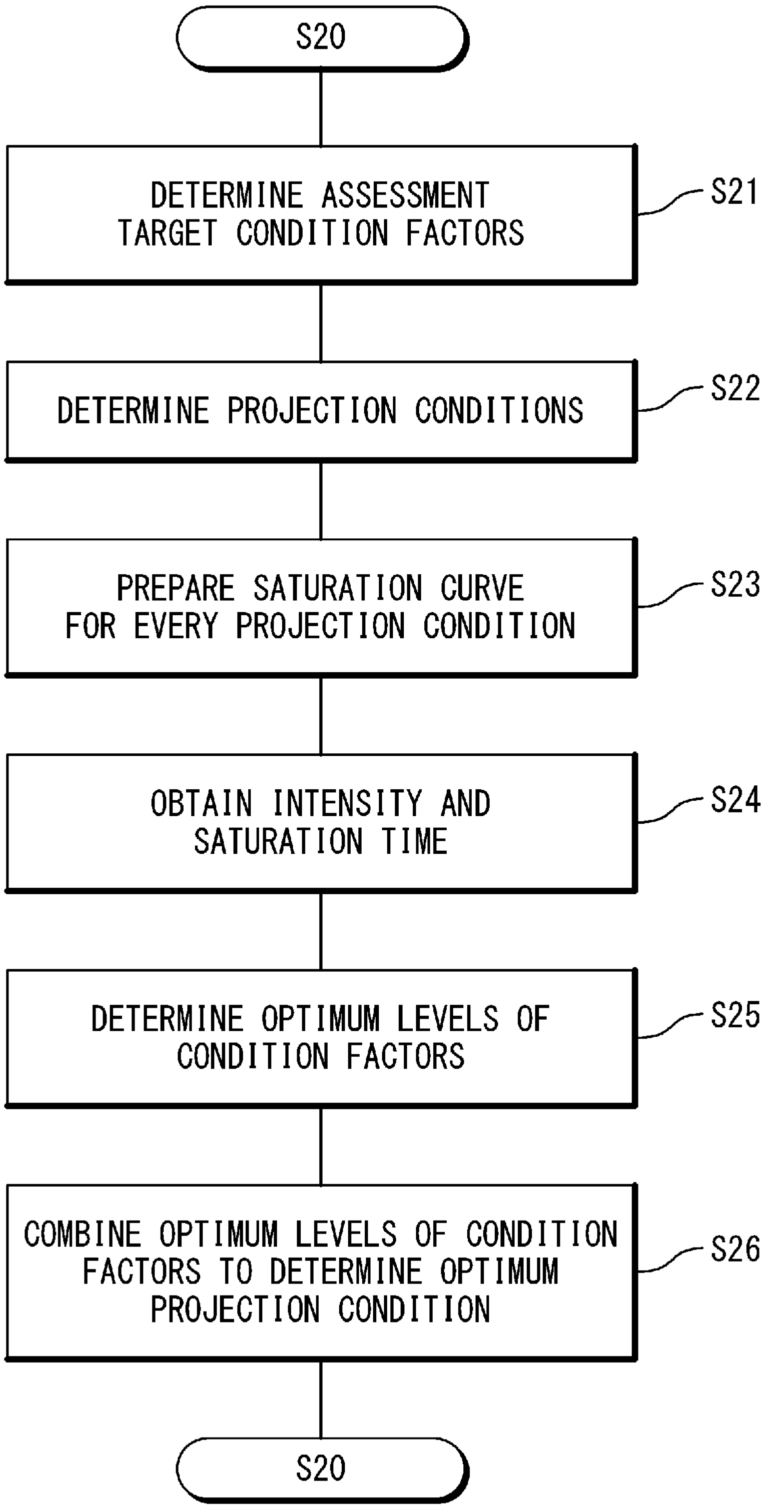

S20
DETERMINE ASSESSMENT TARGET CONDITION FACTORS
S21
DETERMINE PROJECTION CONDITIONS
S22
PREPARE SATURATION CURVE FOR EVERY PROJECTION CONDITION
S23
OBTAIN INTENSITY AND SATURATION TIME
S24
DETERMINE OPTIMUM LEVELS OF CONDITION FACTORS
S25
COMBINE OPTIMUM LEVELS OF CONDITION FACTORS TO DETERMINE OPTIMUM PROJECTION CONDITION
S26
S20

Fig. 5

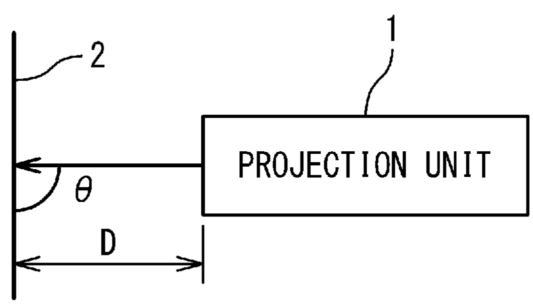


Fig. 6

CONDITION NUMBER	1-1	1-2	1-3
AIR PRESSURE P [MPa]	0. 3	0. 3	0. 3
ANGLE θ	90	90	90
FLOW RATE kg/min	1. 3	4	7
MEDIA	S70	S70	S70
DISTANCE/mm	200	200	200
NOZZLE DIAMETER	9	9	9

Fig. 7

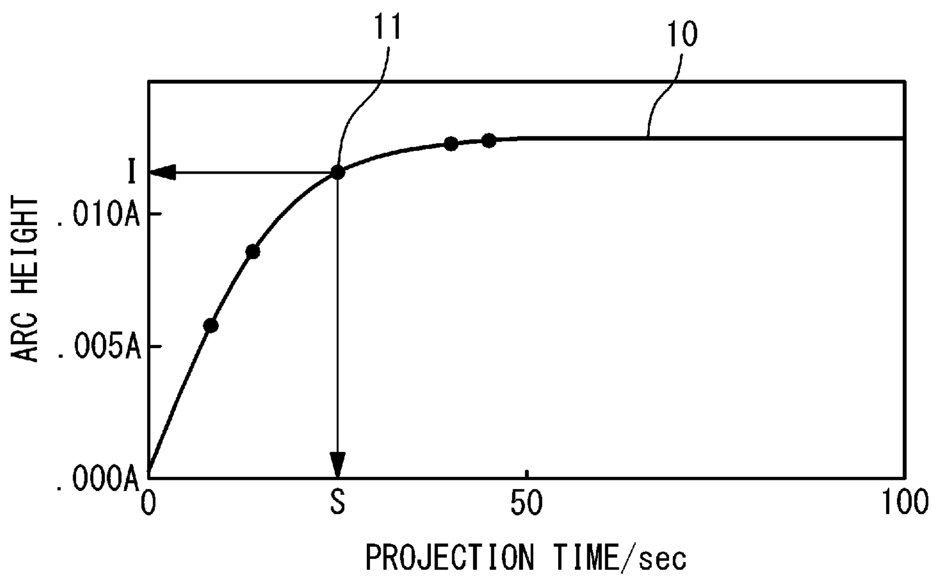

11
10
I
.010A
.005A
.000A
ARC HEIGHT
0
S
50
100
PROJECTION TIME/sec

Fig. 8A

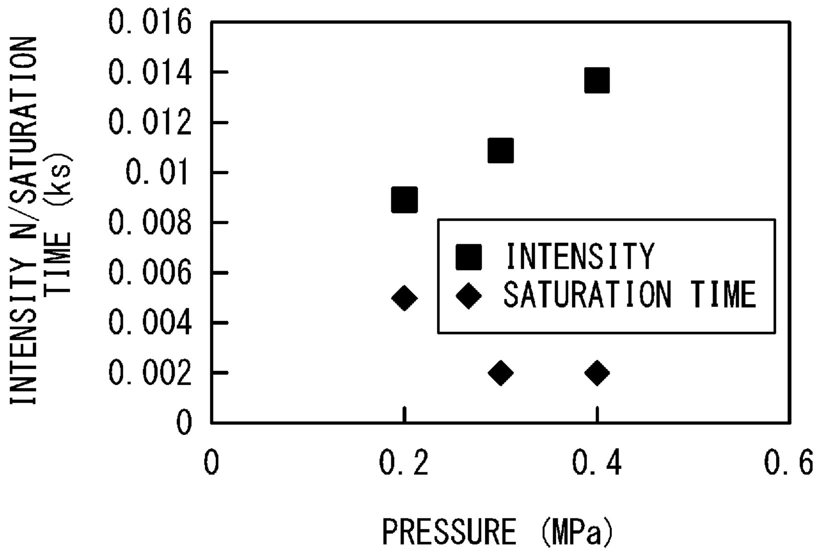

0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
0.2
0.4
0.6
INTENSITY N/SATURATION TIME (ks)
PRESSURE (MPa)
INTENSITY
SATURATION TIME

Fig. 8B

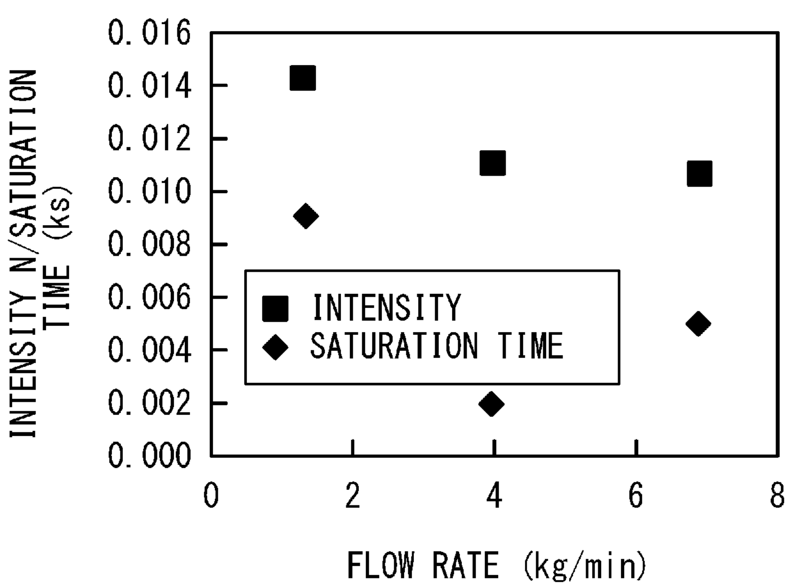

0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
0
2
4
6
8
INTENSITY N/SATURATION TIME (ks)
FLOW RATE (kg/min)
INTENSITY
SATURATION TIME

Fig. 8C

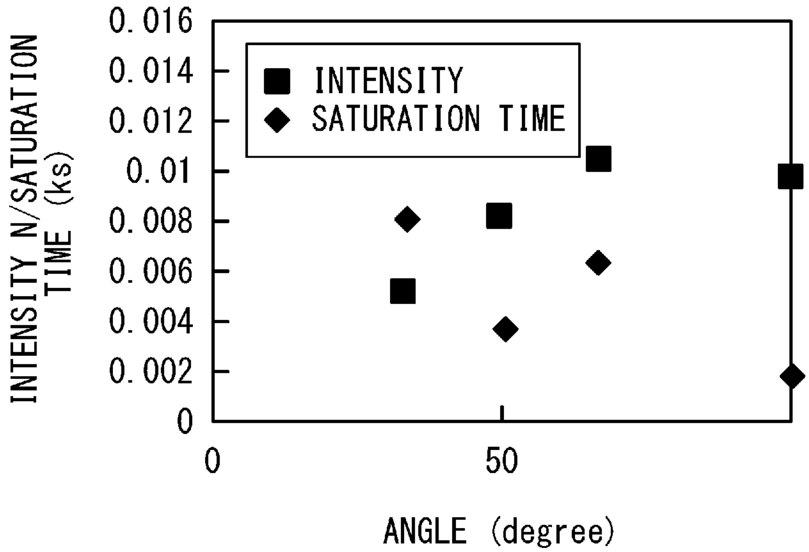

INTENSITY N/SATURATION TIME (ks)
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
INTENSITY
SATURATION TIME
0
50
ANGLE (degree)

Fig. 8D

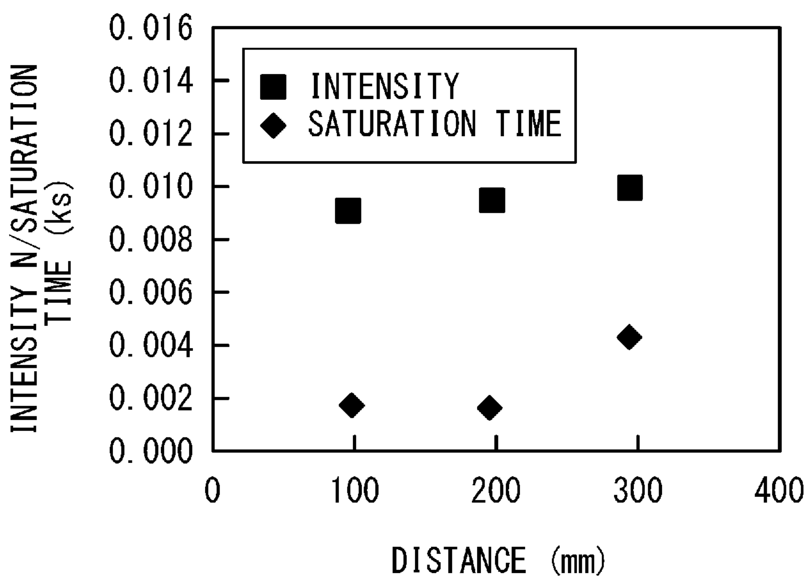

INTENSITY N/SATURATION TIME (ks)
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
INTENSITY
SATURATION TIME
0
100
200
300
400
DISTANCE (mm)

Fig. 9

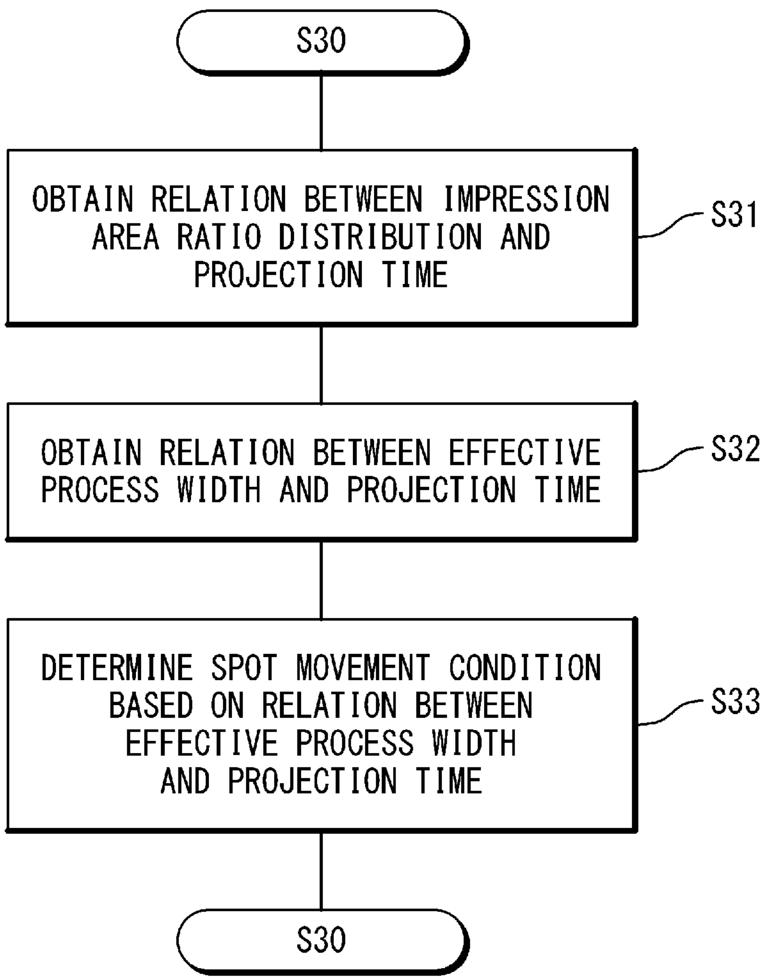

S30
OBTAIN RELATION BETWEEN IMPRESSION AREA RATIO DISTRIBUTION AND PROJECTION TIME
S31
OBTAIN RELATION BETWEEN EFFECTIVE PROCESS WIDTH AND PROJECTION TIME
S32
DETERMINE SPOT MOVEMENT CONDITION BASED ON RELATION BETWEEN EFFECTIVE PROCESS WIDTH AND PROJECTION TIME
S33
S30

Fig. 10

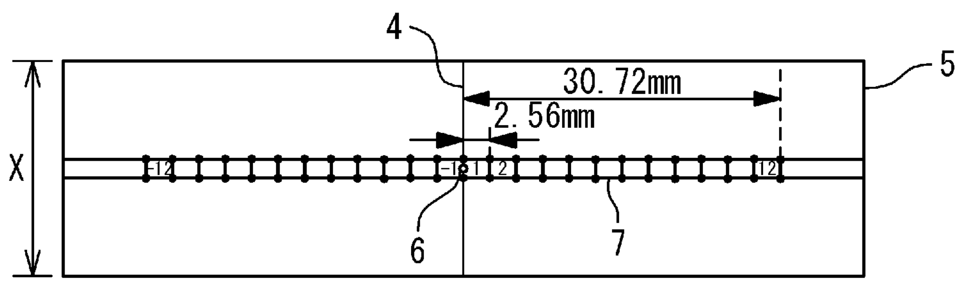
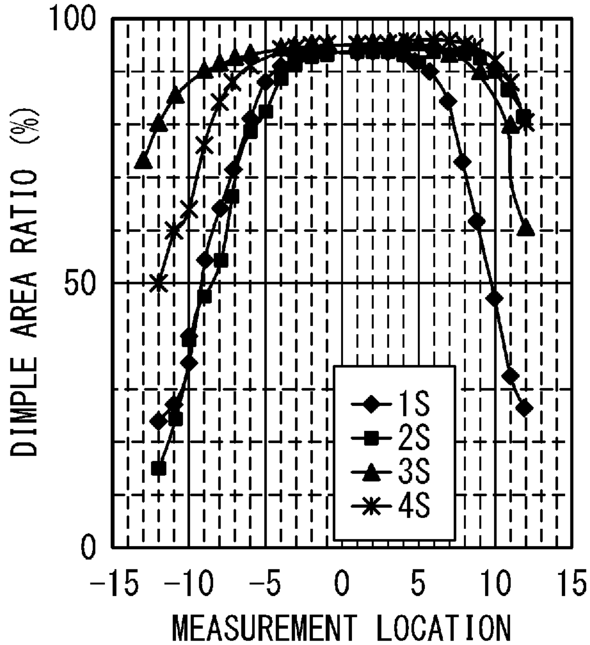


Fig. 11



100
50
0
DIMPLE AREA RATIO (%)
-15
-10
-5
0
5
10
15
MEASUREMENT LOCATION
1S
2S
3S
4S

Fig. 12

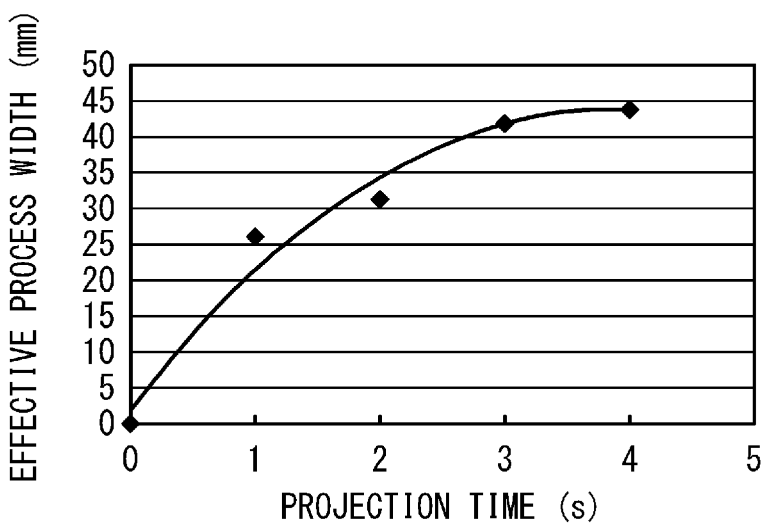

EFFECTIVE PROCESS WIDTH (mm)
50
45
40
35
30
25
20
15
10
5
0
0
1
2
3
4
5
PROJECTION TIME (s)

Fig. 13

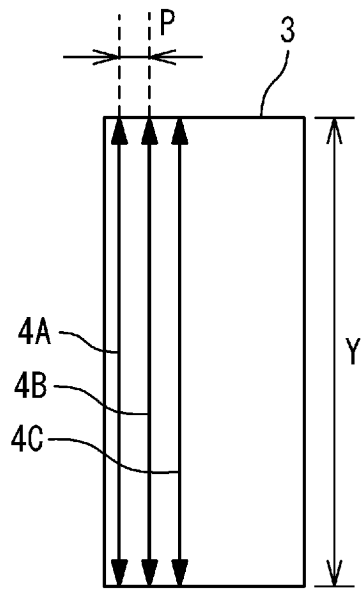


Fig. 14

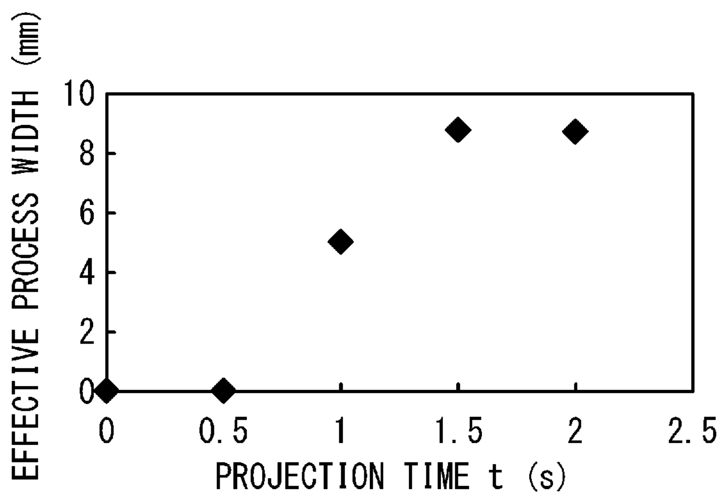

EFFECTIVE PROCESS WIDTH (mm)
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5
PROJECTION TIME t (s)

Fig. 15

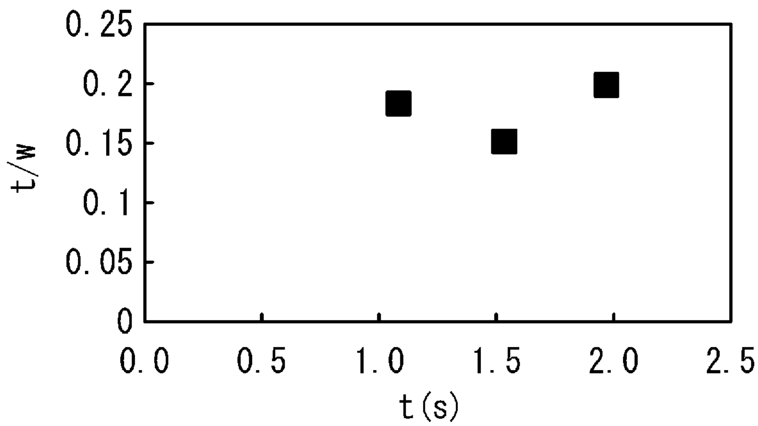

t/w
0.25
0.2
0.15
0.1
0.05
0
0.0
0.5
1.0
1.5
2.0
2.5
t(s)

Fig. 16

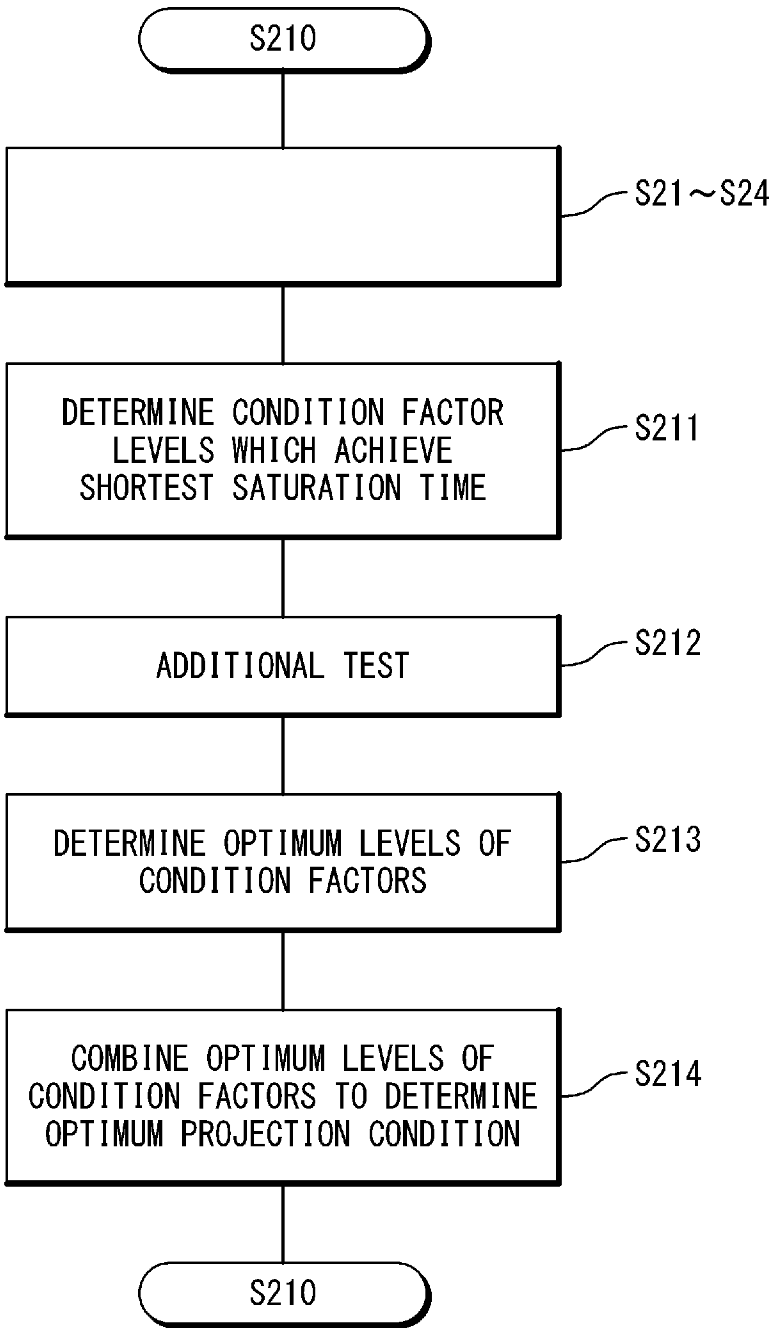

S210
S21～S24
DETERMINE CONDITION FACTOR LEVELS WHICH ACHIEVE SHORTEST SATURATION TIME
S211
ADDITIONAL TEST
S212
DETERMINE OPTIMUM LEVELS OF CONDITION FACTORS
S213
COMBINE OPTIMUM LEVELS OF CONDITION FACTORS TO DETERMINE OPTIMUM PROJECTION CONDITION
S214
S210

Fig. 17

CONDITION NUMBER	1-4	1-5	1-6
AIR PRESSURE P [MPa]	0.3	0.3	0.2
ANGLE θ	90	90	90
FLOW RATE kg/min	3	5	4
MEDIA	S70	S70	S70
DISTANCE/mm	200	200	200
NOZZLE DIAMETER	9	9	9

Fig. 18

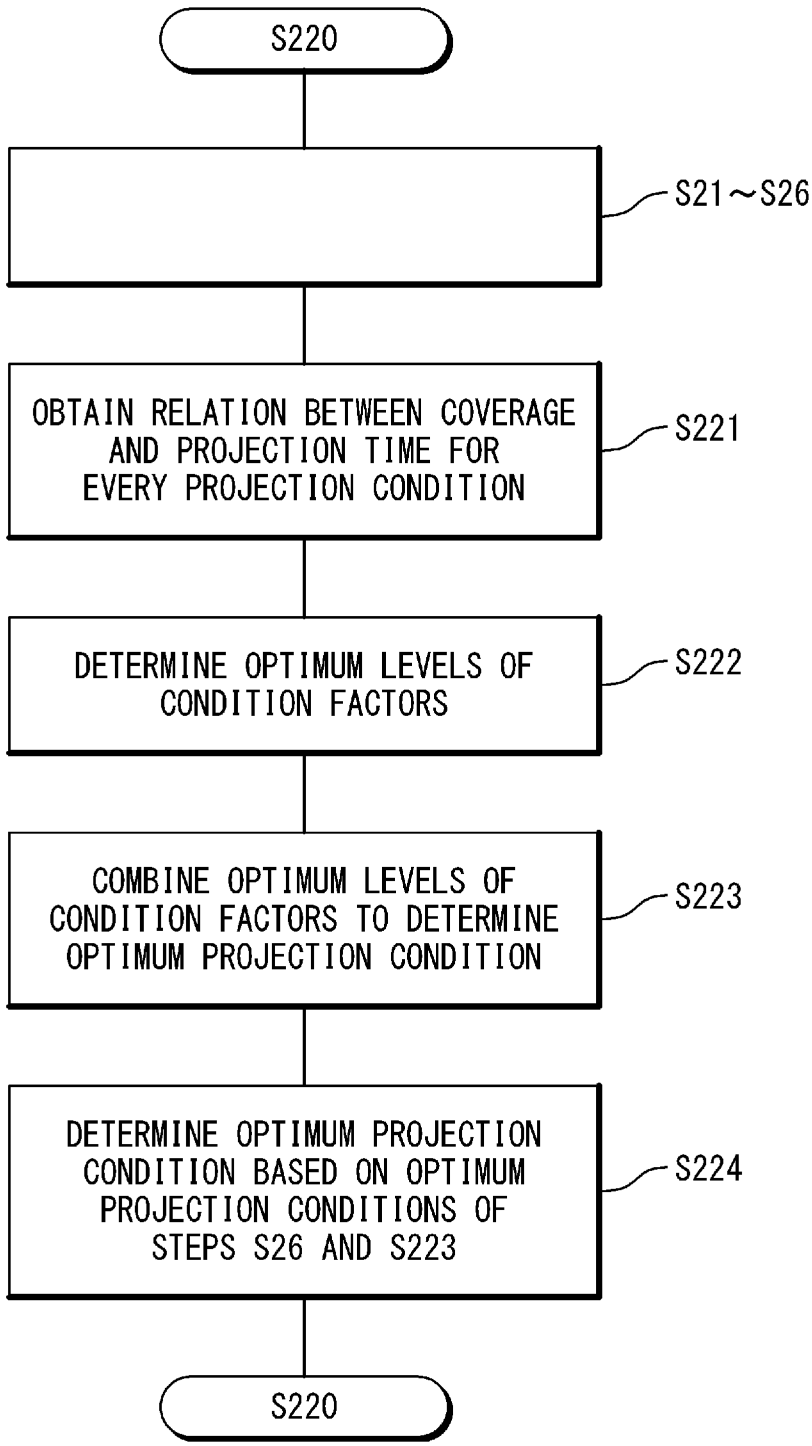
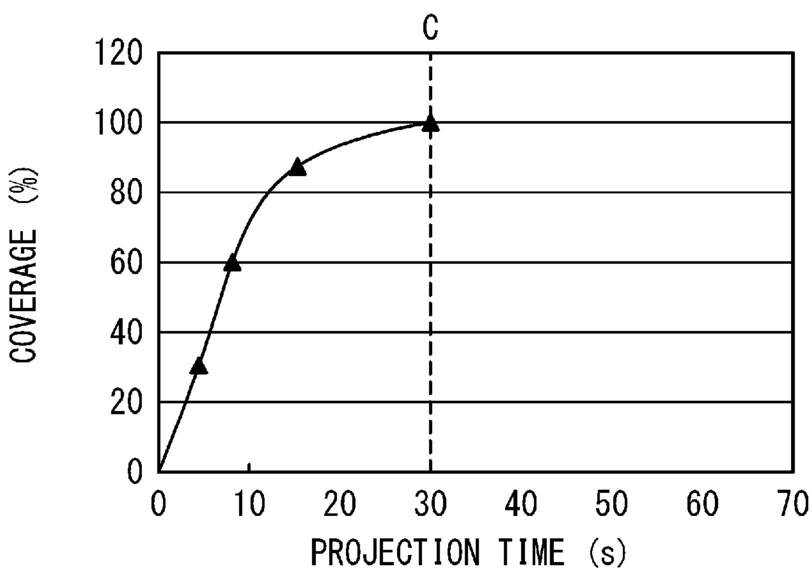

S220
S21～S26
OBTAIN RELATION BETWEEN COVERAGE AND PROJECTION TIME FOR EVERY PROJECTION CONDITION
S221
DETERMINE OPTIMUM LEVELS OF CONDITION FACTORS
S222
COMBINE OPTIMUM LEVELS OF CONDITION FACTORS TO DETERMINE OPTIMUM PROJECTION CONDITION
S223
DETERMINE OPTIMUM PROJECTION CONDITION BASED ON OPTIMUM PROJECTION CONDITIONS OF STEPS S26 AND S223
S224
S220

Fig. 19



C
120
100
80
60
40
20
0
COVERAGE (%)
0
10
20
30
40
50
60
70
PROJECTION TIME (s)

METHOD FOR SETTING SHOT-PEENING PROCESS CONDITION

TECHNICAL FIELD

The present invention relates to a shot peening processing method.

BACKGROUND ART

A shot peening processing method is used to provide a metal surface layer with compressive residual stress. In the shot peening processing method, media (shot media) is projected onto a work.

In a conventional shot peening processing method, after a combination of a shot peening processing apparatus and media is determined, a process condition is determined such that intensity and coverage required for a work can be achieved. An effective and systematic method for reducing a required time for shot peening process is required.

Japanese Patent Publication (JP-P2006-205342A) discloses a conventional method for setting shot peening condition. A relation between weight of shot media projected per unit time and an arc height value when coverage is 100% is obtained by using an air blast type shot-peening apparatus. When the weight of shot media projected per unit time is greater than a certain value, the arc height value is greatly reduced as the weight of shot media projected per unit time is increased. Based on the value, an optimum value of weight of shot media projected per unit time is set.

SUMMARY OF INVENTION

An objective of the present invention is to provide a method for setting shot-peening process condition and a method for manufacturing metal part which reduce required time for shot-peening process.

In a first aspect of the present invention, a method for setting shot-peening process condition includes: a step of obtaining, for each of a plurality of peening conditions for a first combination as a combination of a shot-peening processing apparatus and media, a saturation time based on a saturation curve indicating change in arc height value of Almen strip against projection time; and a step of determining a first optimum peening condition corresponding to the first combination based on the saturation time.

Preferably, condition factors of the plurality of peening conditions include a first condition factor and a second condition factor. The plurality of peening conditions include: a first peening condition; a second peening condition different from the first peening condition in only a level of the first condition factor; a third peening condition; and a fourth peening condition different from the third peening condition in only a level of the second condition factor. The step of determining the first optimum peening condition based on the saturation time includes: a step of determining a level of the first condition factor in the first optimum peening condition based on a first saturation time under the first peening condition and a second saturation time under the second peening condition; and a step of determining a level of the second condition factor in the first optimum peening condition based on a third saturation time under the third peening condition and a fourth saturation time under the fourth peening condition.

Preferably, the shot-peening processing apparatus projects media from a nozzle by using air. The first condition factor and the second condition factor are arbitrary two selected from flow rate of media, pressure of air, distance between the nozzle and a surface to be processed, angle between the nozzle and a surface to be processed, inner diameter of the nozzle, and movement speed of the nozzle.

Preferably, the shot-peening processing apparatus projects media by using an impeller. The first condition factor and the second condition factor are arbitrary two selected from rotation speed of the impeller, distance between the impeller and a surface to be processed, angle between the impeller and a surface to be processed, size of a projection outlet, movement speed of a work, and rotation speed of a work.

Preferably, the above method for setting shot-peening process condition includes: a step of the shot-peening processing apparatus projecting media to a test piece under the first optimum peening condition; a step of obtaining a relation between a distribution of dimpled area ratio in the test piece and projection time; and a step of obtaining, based on the relation between the distribution of the dimpled area ratio and the projection time, a relation between area or width of a region of the test piece, in which the dimpled area ratio is saturated, and the projection time. The dimpled area ratio indicates an area occupied by dimples formed by media per unit area.

Preferably, the above method for setting shot-peening process condition further includes a step of determining a spot movement condition based on the relation between the area or width and the projection time. The spot movement condition indicates a pitch of movement trajectories along which a spot moves. The movement trajectories are parallel to each other. The spot is a region of a work, which is hit by media when the shot-peening processing apparatus processes the work.

Preferably, when intensity corresponding to the first optimum peening condition does not match intensity required for a work, the above method for setting shot-peening process condition further includes: a step of obtaining a saturation time for each of a plurality of peening conditions for a second combination as a combination of a shot-peening processing apparatus and media; and a step of determining a second optimum peening condition corresponding to the second combination based on the saturation time corresponding to the second combination.

Preferably, the above method for setting shot-peening process condition further includes a step of obtaining intensity under the first optimum peening condition.

Preferably, the above method for setting shot-peening process condition further includes: a step of obtaining a coverage time as a projection time required for a coverage of 100% for each of the plurality of peening conditions by using the Almen strip used in the step of obtaining the saturation time; a step of determining a third optimum peening condition corresponding to the first combination based on the coverage time; and a step of determining a fourth peening condition based on the first peening condition and the third peening condition.

In a second aspect of the present invention, a method for setting shot-peening process condition includes: a step of a shot-peening processing apparatus projecting media onto a test piece; a step of obtaining a relation between a distribution of dimpled area ratio in the test piece and projection time; and a step of obtaining, based on the relation between the distribution of the dimpled area ratio and the projection time, a relation between area or width of a region of the test piece, in which the dimpled area ratio is saturated, and the projection time. The dimpled area ratio indicates area occupied by dimples formed by media per unit area.

In a third aspect of the present invention, a method for setting shot-peening process condition includes: a step of obtaining, for each of a plurality of peening conditions for a first combination as a combination of a shot-peening processing apparatus and media, a coverage time as a projection time required for a coverage of 100% based on a saturation curve indicating change in coverage of Almen strip against projection time; and a step of determining an optimum peening condition corresponding to the first combination based on the coverage time.

Preferably, condition factors of the plurality of peening conditions include a first condition factor; and a second condition factor. The plurality of peening conditions include: a first peening condition; a second peening condition different from the first peening condition in only a level of the first condition factor; a third peening condition; and a fourth peening condition different from the third peening condition in only a level of the second condition factor. The step of determining the optimum peening condition based on the coverage time includes: a step of determining a level of the first condition factor in the optimum peening condition based on a first coverage time under the first peening condition and a second coverage time under the second peening condition; and a step of determining a level of the second condition factor in the optimum peening condition based on a third coverage time under the third peening condition and a fourth coverage time under the fourth peening condition.

In a fourth aspect of the present invention, a method for manufacturing metal part includes: a step of determining a shot-peening process condition; and a step of processing a work based on the shot-peening process condition. The step of determining the shot-peening process condition includes: a step of obtaining, for each of a plurality of peening conditions for a first combination as a combination of a shot-peening processing apparatus and media, a saturation time based on a saturation curve indicating change in arc height value of Almen strip against projection time; and a step of determining a first optimum peening condition corresponding to the first combination based on the saturation time.

In a fifth aspect of the present invention, a method for manufacturing metal part includes: a step of determining a shot-peening process condition; and a step of processing a work based on the shot-peening process condition. The step of determining the shot-peening process condition includes: a step of a shot-peening processing apparatus projecting media onto a test piece; a step of obtaining a relation between a distribution of dimpled area ratio in the test piece and projection time; a step of obtaining, based on the relation between the distribution of the dimpled area ratio and the projection time, a relation between area or width of a region of the test piece, in which the dimpled area ratio is saturated, and the projection time; and a step of determining a spot movement condition based on the relation between the area or width and the projection time. The spot movement condition indicates a movement condition of a spot as a region of the work, which is hit by media when the shot-peening apparatus processes the work.

In a sixth aspect of the present invention, a method for manufacturing metal part includes: a step of determining a shot-peening process condition; and a step of processing a work based on the shot-peening process condition. The step of determining the shot-peening process condition includes: a step of obtaining, for each of a plurality of peening conditions for a first combination as a combination of a shot-peening processing apparatus and media, a coverage time as a projection time required for a coverage of 100% based on a saturation curve indicating change in coverage of Almen strip against projection time; and a step of determining an optimum peening condition corresponding to the first combination based on the coverage time.

According to the present invention, there are provided a method for setting shot-peening process condition and a method for manufacturing metal part which reduce required time for shot-peening process.

BRIEF DESCRIPTION OF DRAWINGS

The above and other objects, advantages, and features of the present invention will be more apparent from the description of embodiments taken in conjunction with the accompanying drawings, in which:

FIG. **1** is a flow chart of a shot-peening processing method according to a first embodiment of the present invention;

FIG. **2** is a flow chart of a step of determining a shot-peening process condition;

FIG. **3** is a flow chart of a step of determining an optimum process condition which corresponds to a combination of an apparatus and media;

FIG. **4** is a flow chart of a step of determining an optimum peening condition;

FIG. **5** is a schematic diagram showing a positional relation between a projection unit of a shot-peening processing apparatus and a surface of a working piece;

FIG. **6** is a table showing peening conditions;

FIG. **7** is a graph showing a relation between arc height and projection time;

FIG. **8**A is a graph showing a relation between intensity and pressure and a relation between saturation time and pressure;

FIG. **8**B is a graph showing a relation between intensity and media flow rate and a relation between saturation time and media flow rate;

FIG. **8**C is a graph showing a relation between intensity and projection angle and a relation between saturation time and projection angle;

FIG. **8**D is a graph showing a relation between intensity and projection distance and a relation between saturation time and projection distance;

FIG. **9** is a flow chart of a step of determining a spot movement condition;

FIG. **10** shows a test piece for obtaining a relation between dimpled area ratio distribution and projection time;

FIG. **11** is a graph showing a relation between dimpled area ratio distribution and projection time;

FIG. **12** is a graph showing a relation between effective process width and projection time;

FIG. **13** is a schematic diagram showing spot movement trajectories;

FIG. **14** is a graph showing a relation between effective process width and projection time;

FIG. **15** is a graph showing a relation between processing time per unit area and projection time;

FIG. **16** is a flow chart of a step of determining an optimum peening condition according to a second embodiment of the present invention;

FIG. **17** is a table showing peening conditions;

FIG. **18** is a flow chart of a step of determining an optimum peening condition according to a third embodiment of the present invention; and

FIG. **19** is a graph showing a relation between coverage and projection time.

DESCRIPTION OF EMBODIMENTS

With reference to the accompanying drawings, embodiments of a method for setting shot-peening process condition and a shot-peening processing method according to the present invention will be described below.

First Embodiment

FIG. **1** is a flow chart of a shot-peening processing method according to a first embodiment of the present invention. The shot-peening processing method includes a step S**1** and a step S**2**. In the step S**1**, a shot-peening process condition is determined. In the step S**2**, a work is processed based on the condition determined in the step S**1**.

With reference to FIG. **2**, the step S**1** of determining shot-peening process condition includes steps S**11** to S**13**. In the step S**11**, a combination of a shot-peening processing apparatus and media is determined. Here, a shot-peening processing apparatus as an assessment target is determined concretely, for example, by specifying a model of an air blast type shot-peening processing apparatus or a model of a mechanical type shot-peening processing apparatus. The air blast type shot-peening processing apparatus projects media from a nozzle by using air. The mechanical type shot-peening apparatus projects media by using an impeller. Then, media is determined from a plurality kinds of media which can be used by the determined shot-peening processing apparatus and are controlled based on certain quality standard. By using media controlled based on certain quality standard, reproducibility of shot-peening process is secured. The media controlled based on certain quality standard is, for example, media specified by public standard. In the step S**12**, an optimum process condition corresponding to the combination determined in the step S**11** is determined. In the step S**13**, it is judged whether an intensity required for a work is satisfied, when the work is processed by using the shot-peening processing apparatus and the media determined in the step S**11** based on the optimum process condition determined in the step S**12**. When the intensity requirement is not satisfied, the method returns to the step S**11**. When the intensity requirement is satisfied, the method proceeds to the step S**2**.

With reference to FIG. **3**, the step S**12** of determining an optimum process condition includes steps S**20** and S**30**. In the step S**20**, an optimum process condition is determined for a case that the shot-peening processing apparatus determined in the step S**11** projects the media determined in the step S**11**. In the step S**30**, a spot movement condition is determined. The spot movement condition indicates a movement condition of a spot as a region of a work which is hit by the media when the shot-peening processing apparatus determined in the step S**11** processes the work.

With reference to FIG. **4**, the step S**20** of determining an optimum process condition includes steps S**21** to S**26**.

In the step S**21**, assessment target condition factors are determined. For example, assessment target condition factors in a case of an air blast type shot-peening processing apparatus are: flow rate (kg/min) of media; air pressure (MPa); distance (projection distance) between a nozzle as a projection unit of the air blast type shot-peening processing apparatus and a surface of a work; angle (projection angle) between the nozzle and the work surface; inner diameter of the nozzle; and movement speed of the nozzle. For example, assessment target condition factors in a case of a mechanical type shot-peening processing apparatus are: rotation speed (rpm) of an impeller as a projection unit of the mechanical type shot-peening processing apparatus; distance (projection distance) between the impeller and a surface of a work; angle (projection angle) between the impeller and the work surface; size of a projection outlet from which the media is injected to the work surface; movement speed of the work; and rotation speed (rpm) of the work.

With reference to FIG. **5**, there are shown a distance D between the projection unit **1** of the shot-peening processing apparatus and the work surface **2**, and the angle • between the projection unit **1** and the work surface **2**.

In the step S**22**, a plurality of peening conditions is determined. For example, condition factors of the plurality of peening conditions include the flow rate, the pressure, the angle, the distance and the like as the condition factors determined in the step S**21**. FIG. **6** shows peening conditions **1-1** to **1-3** included in the plurality of peening conditions. The peening conditions **1-1** to **1-3** are different from each other in only the level of the flow rate but are the same in levels of the other condition factors. The plurality of peening conditions includes a peening condition group in which only the level of the pressure is different, a peening condition group in which only the level of the angle is different, a peening condition group in which only the level of the distance is different, and the like.

In the step S**23**, a saturation curve indicating change in arc height value of Almen strip against projection time is prepared for each of the plurality of peening conditions determined in the step S**22**. FIG. **7** shows a saturation curve **10** obtained based on arc height values when projection time is 5 seconds, 10 seconds, 20 seconds, and 40 seconds under a certain peening condition.

In the step S**24**, intensity and saturation time for each of the peening conditions determined in the step S**22** are obtained based on the saturation curves obtained in the step S**23**. With reference to FIG. **7**, a method for obtaining intensity and saturation time will be described. According to AMS-S-13165A of National Aerospace Standard, a point **11** on the saturation curve **10**, for which increase in the arc height value is 10% or below when the projection time is doubled, is referred to as a saturation point **11**, the arc height value at the saturation point **11** is intensity I, and the projection time at the saturation point **11** is saturation time S.

In the step S**25**, an optimum level of each condition factor is determined such that the shortest saturation time is attained. For example, FIG. **8**A shows a relation between intensity and pressure and a relation between saturation time and pressure, which are obtained as described above. Based on the relation between saturation time and pressure, the optimum level of pressure is determined to be 0.3 MPa or above. FIG. **8**B shows a relation between intensity and flow rate and a relation between saturation time and flow rate, which are obtained as described above. Based on the relation between saturation time and flow rate, the optimum level of flow rate is determined to be 4 kg/min. FIG. **8**C shows a relation between intensity and angle and a relation between saturation time and angle, which are obtained as described above. Based on the relation between saturation time and angle, the optimum level of angle is determined to be 90 degrees. FIG. **8**D shows a relation between intensity and distance and a relation between saturation time and distance, which are obtained as described above. Based on the relation between saturation time and distance, the optimum level of distance is determined to be 200 mm or shorter.

In the step S**26**, an optimum peening condition corresponding to the combination of the shot-peening processing apparatus and the media determined in the step S**11** is determined. The optimum peening condition is a combination of the optimum levels of the respective condition factors, which are determined in the step S**25**.

The peening condition **1-2** shown in FIG. **6** corresponds to the optimum peening condition determined in the step S**26**. Therefore, intensity under the optimum peening condition is obtained from FIG. **8**B. Therefore, the intensity which can be obtained effectively (in a short processing time) by using the combination of the shot-peening apparatus and the media determined in the step S**11** is 0.011 inch N from FIG. **8**B. Note that it is also possible to obtain intensity under the optimum peening condition by conducting new tests.

After the step S**26**, the method proceeds to the step S**30**.

As mentioned above, based on the saturation time, the optimum peening condition is determined under which a processing time is short in processing with the use of the combination determined in the step S**11**. In general, it is considered that coverage time required for the coverage of 100% is shorter as the saturation time is shorter. The saturation time is easily determined as compared to the coverage time.

By optimizing the spot movement condition, the processing time can further be reduced. The step S**30** of determining a spot movement condition will be described below.

With reference to FIG. **9**, the step S**30** includes steps S**31** to S**33**.

The step S**31** will be described. FIG. **10** shows a test piece **5** used in the step S**31**. The test piece **5** is an Almen strip or a plate made of the same material as the work. It is preferable that the test piece **5** should be sufficiently larger compared with an effective process width (area) which will be mentioned later. In the step S**31**, the shot-peening processing apparatus determined in the step S**11** projects the media determined in the step S**11** onto the test piece **5** under the optimum peening condition determined in the step S**20**. At this time, approximately three levels of projection time are set within a range including the saturation time under the optimum peening condition, for example. Here, the projection unit of the shot-peening processing apparatus and the test piece **5** may relatively move under a predetermined condition. In this case, for example, the projection unit moves parallel or swings such that a spot as a region which is hit by the media moves forward and backward along a center line **4** of the test piece **5**. The length of the test piece **5** in the direction of the center line **4** is X.

In the step S**31**, the surface of the test piece **5**, onto which the projection is performed, is observed by using a magnifying glass, and dimpled area ratio is calculated for each of a plurality of area ratio calculation regions **7** defined on the surface of the test piece **5**. The plurality of area ratio calculation regions **7** are arranged on the both sides of the center line **4** of the test piece **5** along a straight line crossing the center line **4** at a center position **6**. The plurality of area ratio calculation regions **7** are regions of the same shape and the same size. Each area ratio calculation region **7** is a rectangular region of 2.56 mm square, for example. Numbers indicating measurement locations of the area ratio calculation regions **7** are shown in the figure. The absolute value of the number is greater as the location is farther from the center position **6**. The sign of the number is positive when the measurement location is in one side of the center line **4** or negative when the measurement location is in the other side of the center line **4**. The dimpled area ratio indicates area occupied by impressions (dimples) formed by the media per unit area.

In the step S**31**, a relation between dimpled area ratio distribution in the test piece **5** and projection time is obtained. FIG. **11** shows the relation between dimpled area ratio distribution in the test piece **5** and projection time. The vertical axis and horizontal axis of FIG. **11** are dimpled area ratio and measurement location on the test piece **5**, respectively. In FIG. **11**, for each projection time of 1, 2, 3 and 4 seconds, a relation between dimpled area ratio and measurement location is shown.

In the step S**32**, based on the relation between dimpled area ratio distribution and projection time shown in FIG. **11**, for each projection time of 1, 2, 3 and 4 seconds, a width of a region of the test piece **5**, in which the dimpled area ratio is saturated. The region in which the dimpled area ratio is saturated is a region in which the coverage comes up to 100% or more. The width of the region in which the dimpled area ratio is saturated is referred to as an effective process width. It is also possible to use the area (effective process area) of the region in place of the effective process width. FIG. **12** shows a relation between effective process width and projection time. The vertical axis and horizontal axis of FIG. **12** are effective process width and projection time, respectively. Although the effective process width is increased as the projection time is increased, increase in the effective process width is slower when the projection time exceeds 1 second.

In the step S**33**, a spot movement condition is determined based on the relation between effective process width and projection time of FIG. **12**. With reference to FIG. **13**, when the shot-peening processing apparatus determined in the step S**11** processes the work **3**, a spot as a region of the work **3**, which is hit by the media, is moved forward and backward along each of movement trajectories **4**A to **4**C. The movement trajectories **4**A to **4**C are parallel to each other. Here, a length of the work **3** in the direction of the movement trajectories **4**A to **4**C is Y, and a pitch of the movement trajectories **4**A to **4**C is P. The pitch P is a distance between adjacent two of the movement trajectories **4**A to **4**C. Since the effective process width is 25 mm when the projection time is 1 second in FIG. **12**, the spot movement condition is determined as follows: the pitch P is 25 mm; and projection time for moving the spot forward and backward along each of the movement trajectories **4**A to **4**C is (Y/X) times 1 second.

Another example of the step S**30** will be described. FIG. **14** shows another example of a relation between effective process width w and projection time t. When the projection time t is given, coverage is 100% or more in a rectangular region with a length of X and a width of w. That is to say, area Xw is processed in time t. Since the length X is a constant, processing time per unit area is proportional to t/w. FIG. **15** shows a relation between t/w and t obtained from the relation between effective process width w and projection time t of FIG. **14**. In this case, based on 1.5 seconds as the value of t at which the value of t/w is the smallest and the effective process width of 9 mm in this case, the spot movement condition is determined as follows: the pitch P is 9 mm; and projection time for moving the spot forward and backward along each of the movement trajectories **4**A to **4**C is (Y/X) times 1.5 seconds.

When a work to be processed has concretely been determined, it is preferable that the step S**13** should be performed after the step S**20** and before the step S**30**.

In the step S**20**, it is also possible to fix a level of a specific condition factor and then determine optimum levels of the other condition factors. For example, when projection onto the entire of the surface of work is impossible with the projection angle of 90 degrees due to many convexes and concaves of the surface of the work, the projection angle is fixed at 45 degrees and then optimum levels of the other condition factors are determined.

Second Embodiment

A method for setting shot-peening process condition according to a second embodiment of the present invention is the same as the method for setting shot-peening process condition according to the first embodiment except for a point that the step S**20** is replaced by a step S**210** of determining optimum peening condition.

As shown in FIG. **16**, the step S**210** includes the above-described steps S**21** to S**24** and steps S**211** to S**214**. In the step S**211**, in the same way as the step S**25**, an optimum level of each condition factor is determined such that the shortest saturation time is attained. In the step S**212**, additional tests are performed for the vicinity of the levels judged in the step S**211**.

FIG. **17** shows examples of peening conditions in the additional tests. A peening condition **1-4** is the same as the peening condition **1-2** except for a point that the flow rate is 3 kg/min. A peening condition **1-5** is the same as the peening condition **1-2** except for a point that the flow rate is 5 kg/min. A peening condition **1-6** is the same as the peening condition **1-2** except for a point that the pressure is 0.2 MPa. Intensity and saturation time are obtained for each peening condition.

In the step S**213**, based on the saturation times obtained in the step S**212** and the saturation times obtained in the step S**24**, optimum levels of the respective condition factors are determined.

In the step S**214**, an optimum peening condition corresponding to the combination of the shot-peening processing apparatus and the media determined in the step S**11** is determined. The optimum peening condition is a combination of the optimum levels of condition factors determined in the step S**213**.

Third Embodiment

A method for setting shot-peening process condition according to a third embodiment of the present invention is the same as the method for setting shot-peening process condition according to the first or second embodiment except for points that the step S**20** is replaced by a step S**220** and the step S**30** is eliminated.

With reference to FIG. **18**, the step S**220** includes the above-described steps S**21** to S**26** and steps S**221** to S**224**. In the step S**221**, by using the Almen strips used in the step S**23**, under each of the plurality of peening conditions, a relation between coverage of the entire surface of the Almen strip and projection time is obtained. The coverage is determined based on comparison between photographs for coverage judgment as seen in the appendix of JIS B 2711 and the surface of the Almen strip, for example. Then, for each peening condition, a saturation curve indicating change in coverage against projection time as shown in FIG. **19** is obtained. The vertical axis and horizontal axis of FIG. **19** are coverage and projection time, respectively. Based on the saturation curve, coverage time C as projection time required for the coverage of 100% is obtained. In this way, coverage time is obtained for each of the plurality of peening conditions.

In the step S**222**, optimum levels of the respective condition factors are determined such that the shortest coverage time is attained.

In the step S**223**, an optimum peening condition corresponding to the combination of the shot-peening processing apparatus and the media determined in the step S**11** is determined. The optimum peening condition is a combination of the optimum levels of condition factors determined in the step S**222**.

In the step S**224**, an optimum peening condition is determined based on the optimum peening condition determined in the step S**26** and the optimum peening condition determined in the step S**223**. For example, the optimum peening condition of the step S**224** may be determined by selecting one of the optimum peening condition determined in the step S**26** and the optimum peening condition determined in the step S**223**, or the optimum peening condition of the step S**224** may be determined by modifying the optimum peening condition determined in the step S**26** based on the optimum peening condition determined in the step S**223**.

In the present embodiment, the work is processed in the step S**2** based on the optimum peening condition determined in the step S**224**.

There is a possibility that the coverage time under the optimum peening condition determined based on only saturation time is long. According to the present embodiment, the optimum peening condition is determined such that a short coverage time is certainly attained.

Note that the optimum peening condition may be determined based on only coverage time without determining the optimum peening condition based on saturation time.

The shot-peening processing methods according to the above embodiments can be applied to a method for manufacturing metal part.

The present invention has been described with reference to the embodiments; however, the present invention is not limited to the above embodiments. Various modifications can be applied to the above embodiments.

This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2009-050673, filed on Mar. 4, 2009, the disclosure of which is incorporated herein in its entirely by reference.

The invention claimed is:

1. A method for setting a shot peening process condition comprising:

obtaining, for each of a plurality of peening conditions for a first combination as a combination of a shot peening processing apparatus and media, a saturation time based on a saturation curve indicating a change in an arc height value of an Almen strip with respect to a projection time, each of said plurality of peening conditions specifying values of condition factors;

determining optimum values of said condition factors of a first optimum peening condition corresponding to said first combination from said plurality of peening conditions based on said saturation time; and

determining a spot movement condition based on a relation between a projection time of said media and an area or a width of a region of a test piece, where a dimpled area rate is saturated,

wherein said condition factors of said plurality of peening conditions include:

a first condition factor; and

a second condition factor;

wherein said plurality of peening conditions includes:

a first peening condition;

a second peening condition different from said first peening condition in only said value of said first condition factor;

a third peening condition; and

a fourth peening condition different from said third peening condition in only said value of said second condition factor;

wherein said determining said optimum values of said condition factors of said first optimum peening condition based on said saturation time includes:

determining said optimum value of said first condition factor in said first optimum peening condition based on a first saturation time under said first peening condition and a second saturation time under said second peening condition; and

determining said optimum value of said second condition factor in said first optimum peening condition based on a third saturation time under said third peening condition and a fourth saturation time under said fourth peening condition;

wherein said shot peening processing apparatus projects said media from a nozzle by using air; and

wherein said first condition factor and said second condition factor are two of a flow rate of said media, a pressure of said air, an inner diameter of said nozzle, and a movement speed of said nozzle.

2. The method for setting said shot peening process condition according to claim **1**, wherein said determining said spot movement condition comprises:

said media to said test piece under said first optimum peening condition by said shot peening processing apparatus;

obtaining a relation between a distribution of said dimpled area rate in said test piece and said projection time; and

obtaining, based on said relation between said distribution of said dimpled area rate and said projection time, a relation between said area or said width of said region of said test piece, in which said dimpled area rate is saturated, and said projection time,

wherein said dimpled area rate indicates an area occupied by dimples formed by said media per unit area.

3. The method for setting said shot peening process condition according to claim **2**, wherein said determining said spot movement condition further comprises:

determining said spot movement condition based on said relation between said area or said width of said region of said test piece and said projection time,

wherein said spot movement condition indicates a pitch of movement trajectories along which a spot moves,

wherein said movement trajectories are parallel to each other, and

wherein said spot is a region of a work, which is hit by said media when said shot peening processing apparatus processes said work.

4. The method for setting said shot peening process condition according to claim **1**, further comprising, when an intensity corresponding to said first optimum peening condition does not match an intensity required for a work:

obtaining a saturation time for each of a plurality of peening conditions for a second combination as a combination of said shot peening processing apparatus and said media; and

determining a second optimum peening condition corresponding to said second combination based on said saturation time for each of said plurality of peening conditions for said second combination.

5. The method for setting said shot peening process condition according to claim **1**, further comprising obtaining an intensity under said first optimum peening condition.

6. The method for setting said shot peening process condition according to claim **1**, further comprising:

obtaining a coverage time as a projection time required for a coverage of 100% for each of said plurality of peening conditions by using said Almen strip used in said obtaining said saturation time;

determining a third optimum peening condition corresponding to said first combination based on said coverage time; and

determining said fourth peening condition based on said first peening condition and said third peening condition.

7. A method for manufacturing a metal part comprising:

determining a shot peening process condition; and

processing a work based on said shot peening process condition,

wherein said determining said shot peening process condition includes:

obtaining, for each of a plurality of peening conditions for a first combination as a combination of a shot peening processing apparatus and media, a saturation time based on a saturation curve indicating a change in an arc height value of an Almen strip with respect to a projection time, each of said plurality of peening conditions specifying values of condition factors;

determining optimum values of said condition factors of a first optimum peening condition corresponding to said first combination from said plurality of peening conditions based on said saturation time; and

determining a spot movement condition based on a relation between a projection time of said media and an area or a width of a region of a test piece, where a dimpled area rate is saturated,

wherein said condition factors of said plurality of peening conditions include a first condition factor and a second condition factor;

wherein said plurality of peening conditions includes:

a first peening condition;

a second peening condition different from said first peening condition in only said value of said first condition factor;

a third peening condition; and

a fourth peening condition different from said third peening condition in only said value of said second condition factor;

wherein said determining said optimum values of said condition factors of said first optimum peening condition based on said saturation time includes:

determining said optimum value of said first condition factor in said first optimum peening condition based on a first saturation time under said first peening condition and a second saturation time under said second peening condition; and

determining said optimum value of said second condition factor in said first optimum peening condition based on a third saturation time under said third peening condition and a fourth saturation time under said fourth peening condition;

wherein said shot peening processing apparatus projects said media from a nozzle by using air; and

wherein said first condition factor and said second condition factor are two of a flow rate of said media, a pressure of said air, an inner diameter of said nozzle, and a movement speed of said nozzle.

8. The method for manufacturing said metal part according to claim **7**, wherein said determining said spot movement condition comprises:

projecting said media to said test piece under said first optimum peening condition by said shot peening processing apparatus;

obtaining a relation between a distribution of said dimpled area rate in said test piece and said projection time; and

obtaining, based on said relation between said distribution of said dimpled area rate and said projection time, a relation between said area or said width of said region of said test piece, in which said dimpled area rate is saturated, and said projection time, wherein said dimpled area rate indicates an area occupied by dimples formed by said media per unit area.

9. The method for manufacturing said metal part according to claim **8**, wherein said determining said spot movement condition further comprises:

determining said spot movement condition based on said relation between said area or said width of said region of said test piece and said projection time,

wherein said spot movement condition indicates a pitch of movement trajectories of a spot as a region of said work which is hit by said media when said shot peening processing apparatus processes said work, and

wherein said movement trajectories are parallel to each other.

10. The method for manufacturing said metal part according to claim **7**, further comprising, when an intensity corresponding to said first optimum peening condition does not match an intensity required for a said work:

obtaining a saturation time for each of a plurality of peening conditions for a second combination as a combination of said shot peening processing apparatus and said media; and

determining a second optimum peening condition corresponding to said second combination based on said saturation time corresponding to said second combination.

11. The method for manufacturing said metal part according to claim **7**, further comprising obtaining an intensity under said first optimum peening condition.

12. The method for manufacturing said metal part according to claim **7**, further comprising:

obtaining a coverage time as a projection time required for a coverage of 100% for each of said plurality of peening conditions by using said Almen strip used in said obtaining said saturation time;

determining a third optimum peening condition corresponding to said first combination based on said coverage time; and

determining said fourth peening condition based on said first peening condition and said third optimum peening condition.

13. A method for setting a shot peening process condition comprising:

obtaining, for each of a plurality of peening conditions for a first combination as a combination of a shot peening processing apparatus and media, a saturation time based on a saturation curve indicating a change in an arc height value of an Almen strip with respect to a projection time, each of said plurality of peening conditions specifying values of condition factors;

determining optimum values of said condition factors of a first optimum peening condition corresponding to said first combination from said plurality of peening conditions based on said saturation time; and

determining a spot movement condition based on a relation between a projection time of said media and an area or a width of a region of a test piece, where a dimpled area rate is saturated,

wherein said condition factors of said plurality of peening conditions include:

a first condition factor; and

a second condition factor;

wherein said plurality of peening conditions includes:

a first peening condition;

a second peening condition different from said first peening condition in only said value of said first condition factor;

a third peening condition; and

a fourth peening condition different from said third peening condition in only said value of said second condition factor;

wherein said determining said optimum values of said condition factors of said first optimum peening condition based on said saturation time includes:

determining said optimum value of said first condition factor in said first optimum peening condition based on a first saturation time under said first peening condition and a second saturation time under said second peening condition; and

determining said optimum value of said second condition factor in said first optimum peening condition based on a third saturation time under said third peening condition and a fourth saturation time under said fourth peening condition; and

wherein said shot peening processing apparatus projects said media by using an impeller; and

wherein said first condition factor and said second condition factor are two of a rotation speed of said impeller, a distance between said impeller and a surface to be processed, an angle between said impeller and said surface to be processed, a size of a projection outlet, a movement speed of a work, and a rotation speed of said work.

14. The method for setting said shot peening process condition according to claim **13**, wherein said determining said spot movement condition comprises:

projecting said media to said test piece under said first optimum peening condition by said shot peening processing apparatus;

obtaining a relation between a distribution of said dimpled area rate in said test piece and said projection time; and

obtaining, based on said relation between said distribution of said dimpled area rate and said projection time, a relation between said area or said width of said region of said test piece, in which said dimpled area rate is saturated, and said projection time,

wherein said dimpled area rate indicates an area occupied by dimples formed by said media per unit area.

15. The method for setting said shot peening process condition according to claim **14**, wherein said determining said spot movement condition further comprises:

determining said spot movement condition based on said relation between said area or said width of said region of said test piece and said projection time,

wherein said spot movement condition indicates a pitch of movement trajectories along which a spot moves,

wherein said movement trajectories are parallel to each other, and

wherein said spot is a region of said work, which is hit by said media when said shot peening processing apparatus processes said work.

16. The method for setting said shot peening process condition according to claim **13**, further comprising, when an intensity corresponding to said first optimum peening condition does not match an intensity required for said work:

obtaining a saturation time for each of a plurality of peening conditions for a second combination as a combination of said shot peening processing apparatus and said media; and

determining a second optimum peening condition corresponding to said second combination based on said saturation time for each of said plurality of peening conditions for said second combination.

17. The method for setting said shot peening process condition according to claim 13, further comprising obtaining an intensity under said first optimum peening condition.

18. The method for setting said shot peening process condition according to claim 13, further comprising:

obtaining a coverage time as a projection time required for a coverage of 100% for each of said plurality of peening conditions by using said Almen strip used in said obtaining said saturation time;

determining a third optimum peening condition corresponding to said first combination based on said coverage time; and

determining said fourth peening condition based on said first peening condition and said third peening condition.

19. A method for manufacturing a metal part comprising:

determining a shot peening process condition; and

processing a work based on said shot peening process condition,

wherein said determining said shot peening process condition includes:

obtaining, for each of a plurality of peening conditions for a first combination as a combination of a shot peening processing apparatus and media, a saturation time based on a saturation curve indicating a change in an arc height value of an Almen strip with respect to a projection time, each of said plurality of peening conditions specifying values of condition factors;

determining optimum values of said condition factors of a first optimum peening condition corresponding to said first combination from said plurality of peening conditions based on said saturation time; and

determining a spot movement condition based on a relation between a projection time of said media and an area or a width of a region of a test piece, where a dimpled area rate is saturated,

wherein said condition factors of said plurality of peening conditions include a first condition factor and a second condition factor;

wherein said plurality of peening conditions includes:

a first peening condition;

a second peening condition different from said first peening condition in only said value of said first condition factor;

a third peening condition; and

a fourth peening condition different from said third peening condition in only said value of said second condition factor;

wherein said determining said optimum values of said condition factors of said first optimum peening condition based on said saturation time includes:

determining said optimum value of said first condition factor in said first optimum peening condition based on a first saturation time under first peening condition and a second saturation time under said second peening condition; and

determining said optimum value of said second condition factor in said first optimum peening condition based on a third saturation time under said third peening condition and a fourth saturation time under said fourth peening condition;

wherein said shot peening processing apparatus projects said media by using an impeller; and

wherein said first condition factor and said second condition factor are two of a rotation speed of said impeller, a distance between said impeller and a surface to be processed, an angle between said impeller and said surface to be processed, a size of a projection outlet, a movement speed of said work, and a rotation speed of said work.

20. The method for manufacturing said metal part according to claim 19, wherein said determining said spot movement condition comprises:

projecting said media to said test piece under said first optimum peening condition by said shot peening processing apparatus;

obtaining a relation between a distribution of said dimpled area rate in said test piece and said projection time; and

obtaining, based on said relation between said distribution of said dimpled area rate and said projection time, a relation between said area or said width of said region of said test piece, in which said dimpled area rate is saturated, and said projection time,

wherein said dimpled area rate indicates an area occupied by dimples formed by said media per unit area.

21. The method for manufacturing said metal part according to claim 20, wherein said determining said spot movement condition further comprises:

determining said spot movement condition based on said relation between said area or said width of said region of said test piece and said projection time,

wherein said spot movement condition indicates a pitch of movement trajectories of a spot as a region of said work which is hit by said media when said shot peening processing apparatus processes said work, and

wherein said movement trajectories are parallel to each other.

22. The method for manufacturing said metal part according to claim 19, further comprising, when an intensity corresponding to said first optimum peening condition does not match an intensity required for said work:

obtaining a saturation time for each of a plurality of peening conditions for a second combination as a combination of said shot peening processing apparatus and said media; and

determining a second optimum peening condition corresponding to said second combination based on said saturation time corresponding to said second combination.

23. The method for manufacturing said metal part according to claim 19, further comprising obtaining an intensity under said first optimum peening condition.

24. The method for manufacturing said metal part according to claim 19, further comprising:

obtaining a coverage time as a projection time required for a coverage of 100% for each of said plurality of peening conditions by using said Almen strip used in said obtaining said saturation time;

determining a third optimum peening condition corresponding to said first combination based on said coverage time; and

determining said fourth peening condition based on said first peening condition and said third optimum peening condition.

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