

Method And System For Processing A Sheet Of Material

FIELD OF INVENTION

5 The present invention relates broadly to a method and system for processing a sheet of material, to a sheet material comprising one or more reed valves, and to a compressor.

BACKGROUND

10 A compressor is an integral and essential part of cooling systems, such as air-conditioning and refrigeration. A compressor generally comprises a piston within a cylinder that is operable to create differential pressure within the cylinder and ambient pressure and reed suction and discharge valves that lead the refrigerant gas into the cylinder to be compressed and to discharge out the compressed refrigerant gas to the
15 discharge plenum of the cylinder head respectively. In this way, the reed valves act as a check valve for a unidirectional flow of the refrigerant gas.

 As the reed valves are subjected to repeated fatigue and stress, the material to be used for the reed valves should have enhanced fatigue strength and high durability.
20 Reed valves are typically manufactured from a stamping operation with a press machine and then tumbled or barreled with a tumbling medium to smoothen the cut edges and also for developing a compressive residual stress on the reed valves' surfaces.

 Nearly all fatigue and stress corrosion failure originates on the surface of the
25 reed valves. Furthermore, it has been shown that cracks will not initiate or propagate in a compressive stress zone. Therefore, the compressive residual stress produced on the reed valves' surfaces has a very important effect on improving the fatigue limit and increasing resistance to corrosion fatigue, stress corrosion cracking, hydrogen assisted cracking, fretting, galling and erosion caused by cavitation.

30 However, the tumbling reed process inherently involves the knocking of the reed valves and the tumbling medium that is prone to cause dents and scratches to the reed valves' surfaces, as shown in FIG. 10. This may create new defects on the reed valves'

surfaces where fatigue breaking could originate and reduce the fatigue strength of the reed valves.

5 The tumbling medium used in the tumbling reed process, such as stone, is relatively large and hence may not be able to easily enter into the narrow part of the reed valves especially at the slit area and may not be able to create an adequate radius at the edges.

10 The tumbling reed process is also more of a random process and very time dependent and time consuming. It needs a long tumbling time in order to achieve consistent compressive stress and radius at the edges. In addition, the compressive residual stress produced by the tumbling reed process is not relatively high, for example approximately in the region of -400MPa for high carbon heat-treated rolled steel and -600MPa for stainless steel, such that the reed valves' lifetime may not be significantly
15 prolonged against repeated fatigue and stress during the operation of the compressor unit.

A need therefore exist to provide a method and system for processing a sheet of material, that seeks to address at least one of the abovementioned problems.

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SUMMARY

According to a first aspect of the present invention there is provided a method of processing a sheet of material, the method comprising the steps of
25 providing a flux of particles for impinging on the sheet of material; and moving the sheet of material relative to the flux of particles such that the flux of particles impinges on selected areas of the sheet of material.

The method may further comprise using a mask having exposed areas
30 corresponding to critical areas of the sheet of material.

The mask may be moved together with the sheet material relative to the flux of particles such that the flux of particles impinges on selected areas of the sheet of material.

The selected areas of the sheet of material may comprise one or more slit areas.

- 5 The selected areas of the sheet of material may comprise one or more maximum load section areas.

10 A first mask may define one or more masking slits for shot peening of said one or more slit areas and a second mask may define one or more maximum load masking areas for shot peening of said one or more maximum load section areas, and the method may comprise sequentially using the first and second masks.

15 The method may further comprise deburring cutting edges of the slits as a result of the impinging particle flux.

 The method may further comprise imparting compressive residual stress to the maximum load bearing areas.

20 The particles may comprise one of a group comprising glass beads, steel shots, stainless steel shots, stainless steel grid, iron powder and aluminium oxide

 The particle dimensions may be within the range of about 0.05 to about 2.8 mm.

25 The sheet of material may comprise reed valves.

30 According to a second aspect of the present invention there is provided a system for processing a sheet of material, the system comprising a source of a flux of particles for impinging on the sheet of material; and means for moving the sheet of material relative to the flux of particles such that the flux of particles impinges on selected areas of the sheet of material.

 The means for moving the sheet may comprise an X-Y table.

The source of particles may comprise the particles dispersed in a compressed fluid discharge.

5 The system may further comprise a mask having exposed areas corresponding to critical areas of the sheet of material.

According to a third aspect of the present invention there is provided a sheet of material comprising reed valves processed as defined in the first aspect.

10 According to a fourth aspect of the present invention there is provided a compressor unit incorporating a sheet of material comprising reed valves as defined in the third aspect.

BRIEF DESCRIPTION OF THE DRAWINGS

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Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

20 FIG. 1 shows a schematic diagram illustrating a side view of a shot peening processing apparatus in accordance with one embodiment of the present invention.

FIGS. 2(a) and 2(b) show schematic diagrams illustrating a top view of a shot peening processing apparatus comprising jig A and jig B respectively in accordance
25 with one embodiment of the present invention.

FIG. 3 is a schematic diagram showing a cross-sectional view of the region of compression and the region of tension under a surface of a material after undergoing a shot peening process of an example embodiment.

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FIGS. 4(a) and 4(b) show schematic diagrams illustrating the top and bottom views respectively of a reed valve after undergoing a shot peening process in accordance with one embodiment of the present invention.

FIG. 5 shows a set of check point measurements of the curvature of the radius created at the edges of a reed valve after the shot peening process in accordance with one embodiment of the present invention.

5 FIG. 6 shows a flowchart illustrating the different operations performed on reed valves in machine 1 to create radius at the edges and in machine 2 to create compressive stress in accordance with one embodiment of the present invention.

10 FIG. 7 shows a schematic diagram illustrating a side view of a jig transport and assembly apparatus in accordance with one embodiment of the present invention.

15 FIG. 8 shows optical microscopy images of a number of reed valves, illustrating dents free parts, after undergoing the shot peening process with different shot media in accordance with one embodiment of the present invention.

FIG. 9 shows a digital image of a reed valve after undergoing a shot peening process in accordance with one embodiment of the present invention.

20 FIG. 10 shows optical microscopy images illustrating possible dent marks and scratch marks produced by the tumbling reed process.

Figure 11 shows a table showing results of the reliability measurements for reed valves on stainless steel and flapper steel processed by shot peening and by tumbling.

25 Figure 12 shows a flow chart illustrating a method of processing a sheet of material according to an example embodiment.

30 Figure 13 shows a schematic diagram illustrating an exposed interior view of a reciprocating compressor.

DETAILED DESCRIPTION

FIG. 1 shows the side view of the shot peening processing apparatus 112 employed in an example embodiment of the present invention. Small spherical media 102, also referred to as shots, are ejected from the nozzle 100 at a distance 110 towards a multi-layer composite consisting of a specially designed mask, here in the form of a jig including a top jig plate fixture 104 and a bottom jig plate fixture 108, and reed valves 106. The reed valves 106 are clamped in between the top jig plate fixture 104 and the bottom jig plate fixture 108. Examples of shots 102 include glass beads, stainless steel shots and aluminium oxide with a size range of 0.053 - 2.8 in diameter.

The jig top fixture 104, the reed valves 106 and the jig bottom fixture 108 are mounted together and placed on an X-Y table 114. The mounted jig top fixture 104, reed valves 106 and jig bottom fixture 108 can be automated to move in a predetermined pattern, for example as shown by the double-headed arrow 116 in FIG. 1, allowing the high pressure falling shots 102 to fall over, around and through the reed valves 106. The net result is that predictable pattern of relative movement of the shots 102 and the reed valves 106 occur to achieve a more consistent result in terms of creating a radius at the edges and consistent high compressive residual stress in the maximum load section of the reed valves 106.

FIGS. 2(a) and 2(b) show the top view of the shot peening apparatus 112 in example embodiments, illustrating a jig A top fixture 200 and a jig B top fixture 204 respectively. The jig A top fixture 200 and the jig B top fixture 204 are smaller than the reed valves 106, exposing part of the edges of the reed valves 106. The specially designed jig A top fixture 200 allows the shot peening process to be performed on the narrow slit 202, for creating a radius at the edges while blocking the non-critical portions of the reed valves 106 from the impact of the shots 102. The specially designed jig B top fixture 204 allows the shot peening process to be performed on the maximum load section 206 of the reed valves 106, thereby enhancing the compressive residual stress in that section, while blocking other non-critical portions of the reed valves 106 from the impact of the shots 102. These two shot peening processes can be performed at different stages. The jig bottom fixture 108 may include similar design as the jig A top

fixture 200 or jig B top fixture 204 to allow the shot peening process to be performed on the opposite surface of the reed valves 106.

In the shot peening process, the surface of the reed valves 106 is bombarded by shots 102 that are dispersed within a compressed fluid discharge from the nozzle 100. Each piece of the shots 102 striking the reed valves 106 acts as a tiny peening hammer, imparting to the surface of the reed valves 106 a small indentation or dimple. In order for the dimple to be created, the surface of the reed valves 106 must be yielded in tension. In example embodiments, the areas where the shot peening process has been performed can be discerned from a change in colour/appearance, as shown in FIG. 9. For example, the shot-peened areas of a flapper steel will appear shiny.

FIG. 3 illustrates the region of compression 300 and the region of tension 302 created below the surface of a material, or in this example embodiment of the present invention the reed valves 106, after indentations e.g. 304 upon impact of the shots 102. Below the surface, the material tries to restore its original shape, thereby producing below the indentation e.g. 304, a hemisphere 300 of cold-worked material highly stressed in compression. In FIG. 3, circles e.g. 306 represent the constituent particle units of the material.

FIG. 4 shows the top and bottom views of the reed valves 106 after the shot peening process. The reed valves 106 comprises a narrow slit 202 which would allow the tongue-like lead section 400 to be moveable during operation within a compressor. The circles 1 – 5 are checkpoints representing the positions where measurements were performed to determine the curvature and consistency of the radius produced at the edges as a result of the deburring effect of the shot peening process. The results of these measurements for reed valves 106 are shown in FIG. 5 with a magnification of $\times 500$ for both axes. The circles e.g. 500 in FIG. 5 are fitted to the measured curvature e.g. 502 in order to evaluate the curvature e.g. 502 of the radius produced at the edges and to determine the consistency in the radius size produced. In FIG. 5, the fitting of circles e.g. 500 that are relatively large to the curvature e.g. 502 demonstrate a relatively smooth curvature at the edges. This shows that radius at the edges can be produced with the shot peening process. In comparison, the fitting of circles e.g. 500 that are relatively small would otherwise denote comparatively sharp

edges. Sharp edges are prone to dents, which can result in the formation of stress points on the reed valves' surfaces. In contrast, smooth curvature at the edges achieved with the shot peening process can reduce the formation of these stress points. Also, the relative similarity in the circle size e.g. 500 fitted to the curvature e.g. 502 demonstrate the consistency in the radius size at the edges achieved with the shot peening process.

Example embodiments of the invention can provide a method for deburring the cutting edge and also enhance the compressive residual stress in the maximum load section of a compressor's reed valves. The process can provide for a more reliable compressor incorporating reed valves with high fatigue durability as it allows the abrasive media material to be directed at and penetrate selected areas of the reed valves without deforming those parts. The use of jigs for shot peening on selected areas of one or both sides of the surfaces of the reed valves in example embodiments is advantageous in producing deform free parts. Shot peening process performed on the entire surface of one side of the reed valves without the use of jigs can cause warping and deformation of the reed valves. Shot peening process performed on the entire surface of both sides of the reed valves can alleviate this warping effect but slight bends and deformations can still be present on the reed valves.

The shot peening process according to example embodiments of the invention can improve the mechanical properties and can increase resistance to fatigue failure, corrosion fatigue, stress corrosion cracking, hydrogen assisted cracking, fretting, galling, wear and erosion caused by cavitation and hence can provide a considerable increase in part life.

The compressive stress of current reed valves processed by tumbling is only in the region of -400MPa for high carbon heat-treated rolled steel and -600MPa for stainless steel. Depending on the type of media (shots) used in example embodiments of the invention, higher compressive stress can be achieved without deformation of the parts. For example with glass beads at 2bar pressure with a cycle time of 20 sec, more than -730MPa for high carbon heat-treated rolled steel may be achieved. Generally, high carbon heat-treated rolled steel strips, processed in a vacuum furnace with impurity controlled, have been used as the exclusive material for compressor reed valves. Sometimes stainless material of improved fatigue strength is also used, but they have

not been widely used because of their high cost. Reeds with shot peening in example embodiments can improve fatigue strength and can thus allow the opportunity to use low cost high carbon rolled steel instead of the more expensive stainless steel material.

5 TABLE 1 shows the results of the measurements of the compressive stress produced on a flapper steel of thickness 0.512 mm after the shot peening process using different shot media with different dimensions at a pressure of 2.0 – 2.5 bar and a cycle time of 20 seconds using jigs A and B of the example embodiments. The compressive stress can be measured using an X-ray diffraction method for residual stress
10 measurement. As shown in TABLE 1, relatively high compressive stress of more than – 730MPa can be achieved with the shot peening process.

Reed Valve Material : Flapper Steel, Thickness : 0.152 mm				
Media	Size (mm)	Pressure (bar)	Cycle time (sec)	Compressive stress (MPa)
Steel shot	0.6	2.0	20	-437.68 ± 40.04
Stainless steel shot	1.0	2.0	20	-576.17 ± 34.69
Stainless steel grid	1.7 – 2.8	2.0	20	-725.53 ± 43.74
Iron power	0.105 – 0.21	2.5	20	-434.93 ± 36.50
Glass beads	0.253	2.0	20	-730.88 ± 58.90
Aluminium oxide	0.053 – 0.09	2.0	20	-625.10 ± 45.76

TABLE 1

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FIG. 11 shows a table 1100 illustrating the results of the compressive stress measurements for reed valves on stainless steel and flapper steel processed by shot peening and by tumbling. The compressive stress of the reed valves was measured before and after the reed valves had been subjected to flapping or reed displacement
20 operations. The results in Figure 11 show consistent compressive stress, with minimal deterioration, for the reed valves throughout the measurement. The results also show that the reed valves that have been processed using the shot peening process have a relatively higher reliability and compressive stress compared to the reed valves that have been processed using tumbling.

FIG. 6 shows a flowchart illustrating the different operations performed on reed valves 106 in machine 1 to create a radius at the edges and in machine 2 to create compressive stress in accordance with example embodiments of the present invention. Initial operations include checking the thickness 602 to prevent accidental loading of more than one reed valve and loading 604 the reed valves 106 onto the jigs. An assembly 600 of jigs A and a number of reed valves 604, here 4, either formed integrally or separately, is then mounted together. The assembly 600 of jigs A and reed valves 604 are placed into machine 1 606, in which operations comprising station 1 for shot peening 608 to create a radius at the edges, station 2 for air blowing 610 to remove debris and station 3 612 for the separation of the assembly of jig A top and bottom fixtures from the reed valves 604 are performed in sequential order for a cycle time of 20 seconds. In an example embodiment, the shot peening process can be performed on the top and bottom surfaces of the reed valves 604 sequentially using one nozzle and flipping the jigs. In an alternate embodiment, the shot peening process can be performed on both sides of the surfaces of the reed valves 604 simultaneously or sequentially by using one nozzle above the jig and another nozzle below the jig to reduce the cycle time.

The reed valves 604 are then removed from machine 1 606 and the reed valves 604 are subsequently transferred to machine 2 for processing. An assembly 614 of jigs B and the reed valves 604 are then mounted together. The assembly 614 of jigs B and reed valves 604 are then placed into machine 2 616, in which operations comprising station 1 for shot peening 618 for 5 seconds to create compressive stress, station 2 for air blowing 620 to remove debris, station 3 for washing 622, station 4 for air blowing 624 and station 5 626 for the separation of the assembly of jig B top and bottom fixtures from the reed valves 604 are performed in sequential order. The reed valves 604 are then removed from machine 2 616.

FIG. 7 shows an assembling process 700, for example occurring before entry to machine 1 and/or machine 2, in which the top jig fixture 702 drops down and the bottom jig fixture 706 lifts up to secure the reed valves 704, which are then mounted together into an assembly 708 loaded with the reed valve(s) for processing. At the end of the process, for example at the exits of machine 1 and/or machine 2, the

assembly 708 of jigs and reed valves 704 are then separated in which the top jig fixture 702 lifts up and the bottom jig fixture 706 drops down in a separation process 710. The reed valves 704 can then be transferred while the top jig fixture 702 and the bottom jig fixture 706 return to their initial positions in preparation for the next assembling process 700.

FIG. 12 shows a flow chart 1200 illustrating a method of processing a sheet of material according to an example embodiment. At step 1202, a flux of particles is provided for impinging on the sheet of material. At step 1204, the sheet of material is moved relative to the flux of particles such that the flux of particles impinges on selected areas of the sheet of material.

It should be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the machine configurations for the shot peening process as described in the example embodiments without departing from the spirit or scope of the invention as broadly described.

The shot peening process in example embodiments of the invention can advantageously produce dents free parts. As each part can be peened individually, the example embodiments can also eliminate problems associated with the tumbling reed process, where the knocking of parts is inherent in the process. Hence, tumbled reed is prone to cause scratches and dents to the parts. FIG. 8 shows the optical microscopy images with a magnification of $\times 200$ of the reed valves processed by shot peening according to example embodiments with different shot media, indicating dents free parts.

The tumbling reed process is also more of a random process and very time dependent. It needs a long tumbling time in order to achieve consistent compressive stress and radius at the edges. Example embodiments of the invention can address this random problem, as the parts can be shot-peened individually at controlled parameters.

The shot peening process in example embodiments of the invention can use media that are relatively smaller in size, for example glass beads with size of about 0.253mm in diameter. The example embodiments can provide an effective process

especially for thin parts like the reed suction or discharge valves and other designs incorporating small slits of about 0.5mm and below.

Referring to FIG. 13, one application of a sheet material processed using an example embodiment will now be described, more particular reed valves in a compressor 1300. The interior of the compressor 1300 for hermetic gas-compression refrigeration is exposed in FIG. 13. The compressor 1300 comprises a suction inlet pipeline 1302, a suction muffler 1304, and a cylinder head 1308. The suction muffler 1304 is disposed inside the shell 1306 of the compressor 1300. The suction muffler 1304 connects to the cylinder head 1308 which has a suction plenum 1316 and a discharge plenum 1314 at its interior. The suction plenum 1316 receives the gas with lower temperature while the discharge plenum 1314 receives the compressed gas from the cylinder chamber (hidden) at higher temperature. The suction plenum 1316 and the discharge plenum 1314 are connected to a cylinder chamber (hidden) via a suction reed valve 1315 and a discharge reed valve 1317 respectively. The discharge plenum 1314 is further connected to the discharge pipeline 1318 of the compressor 1300 via muffler cover discharge 1310 and discharge line 1312 for discharging compressed gas at high temperature for a refrigeration system.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A method of processing a sheet of material, the method comprising the steps of:

5 providing a flux of particles for impinging on the sheet of material; and
moving the sheet of material relative to the flux of particles such that the flux of particles impinges on selected areas of the sheet of material.

10 2. The method according to claim 1, further comprising using a mask having exposed areas corresponding to critical areas of the sheet of material.

3. The method according to claim 2, wherein the mask is moved together with the sheet material relative to the flux of particles such that the flux of particles impinges on selected areas of the sheet of material.

15 4. The method according to any one of the preceding claims, wherein the selected areas of the sheet of material comprise one or more slit areas.

20 5. The method according to any one of the preceding claims, wherein the selected areas of the sheet of material comprise one or more maximum load section areas.

25 6. The method according to claims 4 and 5, wherein a first mask defines one or more masking slits for shot peening of said one or more slit areas and a second mask defines one or more maximum load masking areas for shot peening of said one or more maximum load section areas, and the method comprises sequentially using the first and second masks.

30 7. The method according to claim 6, further comprising deburring cutting edges of the slits as a result of the impinging particle flux.

8. The method according to claims 6 or 7, further comprising imparting compressive residual stress to the maximum load bearing areas.

9. The method according to any one of the preceding claims, wherein the particles comprise one of a group comprising glass beads, steel shots, stainless steel shots, stainless steel grid, iron powder and aluminium oxide.

5 10. The method according to claim 9, wherein the particle dimensions are within the range of about 0.05 to about 2.8 mm.

11. The method according to any one of the preceding claims, wherein the sheet of material comprises reed valves.

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12. A system for processing a sheet of material, the system comprising:
a source of a flux of particles for impinging on the sheet of material; and
means for moving the sheet of material relative to the flux of particles such
that the flux of particles impinges on selected areas of the sheet of material.

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13. The system according to claim 12, further comprising a mask having
exposed areas corresponding to critical areas of the sheet of material.

14. The system according to claims 12 or 13, wherein the means for
20 moving the sheet comprises an X-Y table.

15. The system according to any one of claims 12 to 14, wherein the
source of particles comprises the particles dispersed in a compressed fluid
discharge.

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16. A sheet of material comprising reed valves processed according to any
one of claims 1 to 11.

17. A compressor unit incorporating a sheet of material comprising reed
30 valves according to claim 16.