On Blanking, Tumbling and Shot-Peening of Compressor Valves

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ON BLANKING, TUMBLING AND SHOT-PEENING
OF COMPRESSOR VALVES

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INTRODUCTION

Valve components used to control direction of flow of fluids through compressors, pump or other pneumatic devices are subjected to dynamic loading. Studies of service valve fractures indicated, that a large proportion failed due to fatigue (1-3). The fatigue cracking originated from stress concentrating defects introduced during the fabrication of the valve or the manufacture of the steel strip.

The work presented below studies the effect of manufacturing operations on the quality of edges and surfaces of valve components made of high-strength strip steels. Limitations in valve processing by blanking and photoetching are shown. Valve treatment by rotating tumbling and vibratory finishing and its positive and negative effects are described. The benefit of residual compressive stresses introduced by tumbling and shot-peening is discussed. Fatigue testing results illustrating the influence of various edge treatments are given and some practical viewpoints on valve processing are indicated.

BLANKING

The valves are mainly produced by blanking. Fig. 1 illustrates a cross-section through the edge perpendicular to the blanked surface.

The shape of the blanked edge deviates in a characteristic manner from the ideal. The material around the upper corner is pulled along with the punch, and resultant rounded surface is called a "wane". Immediately below the wane, the blank surface is smooth and blank. The material in this zone was pressed up against the tool and the surface is newly-formed by plastic deformation. This zone is called the blank zone. When the deformation capacity of the plastically formed zone is exhausted, cracks begin to form at the edges of the punch and the die. These cracks tend to propagate in the direction of the maximum shear stresses, but when these stresses do not meet in the middle, irregular fracture surfaces with residual cracks parallel to the original shear stresses are obtained. This is how the fracture zone arises. A small burr forms at the bottom of the edge and consists of deformed material. This is called blanking burr.

Blanking clearance

Another important blanking term is the blanking clearance. The clearance is the horizontal distance between the punch and the die. If the clearance is very large, the deformation zone will also be large. The blanking forces produce a large bending moment. The cracks created by the tool edges do not meet within the material, Fig. 2. The material follows with the tool and is finally pulled off by tensile stresses. The resultant blanked edge is very course and rough and contains folds, Fig. 3.
FIG. 3 - Folding in the edge after blanking with too large clearance.

If clearance is chosen to match strip thickness, the cracks will meet inside the blanking zone. For strip thickness of 0.15-0.40 mm, the clearance should be equal to approx. 5% of the thickness, but no more than 10%. It should be noted that blanking clearance depends on valve and tool design. A complicated valve shape with holes or slots is more difficult to blank than a simple one with straight edges. A special care must be paid to a tool bearing guidance to prevent a horizontal punch deflection.

If greater precision and straightness of the blanked edge are required, the clearance can be reduced. The hydrostatic pressure in the deformation zone will increase. The cracks initiated by the tool edges may pass by each other. After the primary crack formation, a material bridge remains which is then deformed and cut off by the shearing edges. A secondary blank zone can be formed, Fig. 5, behind which a crack may lie trapped.

Fig. 5 - Secondary blank zone.

Fig. 6 - Profile of edge blanked using newly-ground tool (above) and after 30 000 strokes.

Edge topography and residual stresses

A straight blanked edge without any large topographical irregularities, especially in the fracture zone, may be regarded as the goal of blanking. Besides clearance, tool condition and material parameters can effect the result. A picture of the profile of an edge blanked using a newly-ground tool and an edge blanked with the same tool after 30 000 strokes is shown in Fig. 6. While the edge is straight without any visible change, it is primarily the topography of the fracture zone which exhibits a tendency to become deeper as the edges of the tools become worn.

Fig. 7 shows the residual stresses determined by X-ray diffraction in an edge after gradual tool wear. As is evident, the tensile stresses increase rapidly up to about 20 000 strokes, after which the measured difference was marginal in both directions. The residual stresses are added to the stresses arising during the valve operation.

RESIDUAL STRESS

FIG. 7 - Residual stresses in the edge versus number of strokes. UHB 20, reed thickness 0.30 mm, (0.012 in). Position of measurement: A parallel, B perpendicular to blanking direction.

PHOTOETCHING

Beside blanking the photoetching technique can be used to manufacture a small series of machine components from strip steel. The edge profiles are shown in Fig. 8 and fatigue data performed on photoetched samples are given in last section of this paper. The edge profile deviates from a conventional one. The studies of fractured samples showed that all fatigue cracks started on edges at corrosion pits caused by photoetching, Fig. 9. The pits were analysed by energy dispersive microprobe (EDAX 707). No non-metallic inclusions were detected. The corrosion pits were generated at small carbide particles. An additional edge treatment is necessary in order to remove the etched layer containing the stress raising pits. Tumbled photoetched samples gave improved fatigue strength comparable to conventional edge treatment.

Fig. 8 - Photoetched edge profiles, carbon and stainless valve steels.

Fig. 9 - Fatigue cracking at corrosion pits.
Tumbling

A blanked edge is riddled with cracks, burrs and other stress-raising defects, Fig. 10. In order to improve the edge quality the valve reed is tumbled. Due to an abrasive action the defects are removed, the edge is deburred and radiused.

Fig. 10 - Blanked edge riddled with cracks.

Tumbling practice varies and each valve manufacturer uses his own method. Two different techniques can be distinguished, namely rotating tumbling and vibratory finishing. In rotating or barrel tumbling, the work container is filled to roughly 60% of capacity and rotated so that the load is carried upward to a point where gravity causes it to cascade or slide downwards. Only a fraction of the load is in work motion at any time. In vibratory finishing, the non-rotating open container is used and the entire load is kept in continuous work motion by controlled vibration.

Al-oxide chips are the usual tumbling medium, grain size varying between 2 and 10 mm. The water is added for lubricity and heat conduction. Chemical compounds, regulating pH are used to prevent corrosion.

The abrasive medium grain size should be chosen with respect to the valve shape, size and thickness. For more complicated valves, the mixture of finer and coarser chips is recommended. The finest grain size must pass through all narrow holes and slots exposed to dynamic loading in order to assure a proper edge treatment (1,4,5)

Edge radiusing

A follow-up of changes in the edge was carried out in rotating tumbling. The speed of rotation of the barrel (ø 400 mm) was 24 rpm. Al-oxide chips, grain size 10 mm, compound SiC 3 and water was added. The tumbling time varied between 0 and 40 hours. The tested materials were standard valve grades UHB 20 and UHB Stainless 716, strip thickness 0.305 mm (0.012 in), samples dimension 13 x 150 mm. Changes in the profile of the edge are shown in Fig. 11.

Similar results were recorded for both grades. As is evident from the pictures, an acceptable edge radiusing without burr is obtained after relatively short tumbling times, 5 - 10 hours. Tumbling until the edge rounding radius is 1/3 of the thickness 0.30 mm would require a tumbling time of 20 - 30 hours, which was considered excessive.

The profile depth of the fracture zone, Fig. 1, affects the quality of the edge. Fig. 12 shows a tumbled edge with holes remaining after less successful blanking. It is obvious that topography after blanking is decisive in determining final quality. A properly tumbled edge is shown in Fig. 13.

Fig. 11 - Edge profile changes during tumbling. Strip thickness 0.30 mm (0.012 in). a-h: UHB 20 i: UHB Stainless 716

Fig. 12 - Tumbled edge with holes remaining from blanking.

Fig. 13 - The edge of the reed after proper blanking and tumbling.

In determining tumbling time, it is therefore important to know what anomalies can be obtained in the edge after less successful blanking with, for example, greater clearance, worn tools and the like, and to what degree these are eliminated by finishing treatment.

Surface changes

The material removed from the surface is much less than from the edge (about 200 - 300 times lower). In Fig. 14 surface material removal is shown versus processing time. The following treatment was used: rotating tumbling, for experimental data see previous section and vibratory finishing, machine VMD75, 2 850 vibr/min, centrifugal force 1 000 kp, abrasive medium and chemical compound as in rotating tumbling. The amount of the removed material was determined by weight loss measurements, a correction was done for the edge material removal. It can be seen, that the surface material removal is the linear function of the processing time. The vibratory finishing was found to be more effective than rotating tumbling. Generally speaking, the efficiency of the finishing operations depends on the interaction between abrasive particles and
processed valves, i.e. centrifugal force, rotating or vibrating frequency, abrasive medium, processed component size and shape, etc.

The data shown in Fig. 14 indicate, that UHB Stainless 716 has a higher wear resistance than carbon steel. The curves give a rough idea of the depth of defects which can be influenced by an abrasive finishing treatment. It is obvious that only a very shallow surface irregularities can be ground. The surface layer influenced by processing is the sum of the removed material and deformation hardened surface layer which for a conventional treatment is estimated to about 2 μm. Increasing depth increases the difficulty to eliminate them. The abrasive chip size is very large as compared to the defect size and it is clear that the bottoms of the surface defects where the fatigue cracking is generated are unaffected by the finishing treatment. The following example, Fig. 15, illustrates the surface defect during subsequent rotating tumbling, 0 to 25 hours. The defect depth, 15 μm, was the same before and after tumbling. Another case, Fig. 16, demonstrates the rolled-in metal fragment. After 20 hours processing the defect is unaffected by tumbling and its shape is clearly visible. It could be stated that the notch effect is unchanged despite the abrasive surface treatment. Consequently, the surface quality of the strip steel material is of decisive importance for the resulting valve component surface properties.

![Fig. 14 - Surface removal by finishing treatment.](image)

![Fig. 15 - Surface defect during subsequent tumbling 0, 10 and 25 hours. The defect depth, 15 μm, was unchanged.](image)

The bending fatigue experiments on valve steel samples in delivery condition, i.e. extra bright polished standard surface and tumbled surface verify abovementioned findings. No surface improvement with respect to the fatigue strength was reached by large scale tumbling processing. Therefore, the benefit of the finishing operations can primarily be attributed to the edge treatment. Beside that, the surface anisotropy characterizing polished surface is changed to be more isotropic.

It is well-known, that the surface roughness increases during tumbling. An excessive tumbling may cause a deterioration of the surface smoothness.

![Fig. 16 - Surface defect, rolled-in fragment (right) unaffected by 20 hours tumbling.](image)

Residual stresses

In this section, the surface residual stresses and their distribution below the surface after finishing processing are shown. The significance of the residual stresses for the valve fatigue life is discussed in part on shot-peening.

X-ray stress measurements were made on the surface parallel with the described rotating tumbling and vibratory finishing. Fig. 17 shows the surface residual stresses as a function of processing time. The initial stresses in as-delivered valve steel are compressive, -150 to -200 MN/m² (-30 ksi) for UHB 20 and -500 MN/m² (-70 ksi) for UHB Stainless 716. After processing, shorter than 10 hours the stresses reach a certain "saturation value" and then remain unchanged despite extended treatment. Both rotating tumbling and vibratory finishing introduced the stresses of the same magnitude.

![Fig. 17 - Surface residual stresses as a function of processing time.](image)
For UHB 20, this saturation value lies between -300 and -400 MN/m² (-50 ksi), while for UHB Stainless 716 between -600 and -700 MN/m² (-100 ksi). The difference between these two grades is probably due to differences in deformation hardening caused by plastic deformation in the surface layer. The explanation for the unchanging stress condition during finishing treatment should be sought in the continuous abrasive removal of surface material. Deformation hardening in the newly-formed surface layer seems to be unchanged.

Fig. 18 shows the variation of residual stresses with depth in polished and tumbled UHB 20 and UHB Stainless 716. It should be noted that residual stresses are induced in a very thin surface layer. To take into account the stress relief due to surface removal by electrolytic polishing before each measurement, the correction suggested by Moore and Evans (7) was applied to the calculated stresses at various specimen depths.

The residual stresses induced by shot-peening in the valve component, thickness 0.63 mm, manufactured from 1% carbon steel are shown in Fig. 18.

It is obvious that the beneficial effect produced by residual compressive stresses is determined by their magnitude and depth in relation to the applied tensile stress component and occurring defect size in the peened surface. The effect of residual stresses is to cause the defect or crack to remain closed until the externally applied stress can overcome their action.

In our case, the defects introduced at strip steel manufacture and fabrication of the valve component can be estimated to be smaller than 20 μm (0.0008 in). This means that the compressive stresses, see Fig. 18, are induced deeper than the estimated depth of the surface defects, which can give an improved fatigue performance. However, the residual stresses induced by rotating tumbling or vibratory finishing are low and induced in a very thin surface layer. This layer is smaller than the estimated defect depth and therefore such stresses can hardly influence the fatigue properties of the valve components. The positive effect of the finishing operations is primarily focused on the edge treatment. It should be emphasized that shot-peening is exposed only to the surface while blanked edges are practically unaffected. For that reason an addition finishing is necessary. Another limitation in utilizing of peening technique is the thickness of the valve reed. It was shown that thin reeds are difficult to process without evident flatness deterioration (11).

VARIuos EDE TREATMENT VS FATIGUE STRENGTH

Fig. 19 contains the tensile fatigue testing results on specimens with various edge treatment. More details on experimental technique can be found in ref. (6). The blanked edge showed the lowest, while tumbled samples exhibited the highest fatigue strength. The phototesting technique gave the edge treatment most suitable for direct application.

The residual stresses induced by shot-peening in the valve component, thickness 0.63 mm, manufactured from 1% carbon steel are shown in Fig. 18.
SUMMARY

The effect of manufacturing operations on the quality of the edges and surfaces of compressor valves made of high-strength strip steels was investigated. Dominant factors such as blanking clearance and tool condition determining the edge finish during blanking are discussed. Limitations of the photoetching technique which can be used for processing of a small valve series are shown and necessity of an additional edge treatment removing the edge corrosion pits is emphasized. Valve finishing by rotating tumbling and vibratory finishing is described. A detailed study on edge radiusing and surface changes is presented. In determining of tumbling time it is important to know, what anomalies are obtained in the edge after less successful blanking and to what degree these are eliminated by finishing treatment. It is shown that finishing operation's positive effect can primarily be attributed to the edge treatment. Evidence is given to demonstrate the importance of the strip steel surface quality for the finished valve components. The residual stresses induced by tumbling and shot-peening are discussed with respect to their depth below the surface and true defect size. The tumbling stresses are induced in a very thin surface layer and can hardly improve the valve fatigue properties. The tensile fatigue results illustrating various edge treatment show that the highest fatigue strength was obtained with blanked and tumbled samples.

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REFERENCES


