Impact Fatigue Characteristics of Valve Leaves For Small Hermetic Reciprocating Compressors

Abdullah Can Altunlu
KOC University

Ismail Lazoglu
KOC University

Emre Oguz
Arcelik A.S.

Serkan Kara
Arcelik A.S.

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A. Can ALTUNLU[1], Ismail LAZOGLU[2,*]
Emre OGUZ[3], Serkan KARA[4]

[1]Koc University, Department of Mechanical Engineering,
Manufacturing and Automation Research Center
Sariyer, Istanbul, Turkey
Phone: +90 212 338 1587, Fax: +90 212 338 1548

[2]Koc University, Department of Mechanical Engineering,
Manufacturing and Automation Research Center
Sariyer, Istanbul, Turkey
Phone: +90 212 338 1587, Fax: +90 212 338 1548, ilazoglu@ku.edu.tr

[3]Arcelik A.S., R&D Center, 34950 Tuzla
Istanbul, Turkey
Phone: +90 216 585 8019, Fax: +90 216 423 3045, emre.oguz@arcelik.com

[4]Arcelik A.S., Compressor R&D Center
Compressor Plant, Organize Sanayi Bolgesi, 1. Cadde, Eskisehir, Turkey
Phone: +90 222 213 4654, Fax: +90 222 213 4344, serkan.kara@arcelik.com

* Corresponding Author

ABSTRACT

This paper presents an investigation on the impact fatigue characteristics of valve leaves that are prevalently used in hermetic reciprocating compressors especially for the household type refrigerators. The investigation relates the impact fatigue lifetime of the valve leaves that is the heart of the compressor, with the working temperature, material type (carbon steel, stainless steel and improved stainless steel grade) and tumbling duration after the manufacturing process. The investigation provides a better understanding of the impact fatigue characteristics of valve leaves while designing a high performance compressor to decrease the energy consumption.

A unique automated impact fatigue test system was designed and produced, which enables to carry out impact fatigue tests of the compressor valve leaves under the desired impact velocities. In the test system, original valve plate and valve leaf couple was utilized through the experimentation in order to simulate the real behavior in the compressor. A fixture was designed to mount the valve plate. The main principle of the system is to create pulsating airflow through a high frequency solenoid valve. The impact fatigue life was determined for various impact velocities and at different operating temperatures.

1. INTRODUCTION

Valve leaves must maintain proper working properties in the lifetime of the compressor without failure. Valve leaves are subject to especially bending stresses and impact stresses during the operation of the compressors, therefore bending fatigue strength and impact fatigue strength of the reed valves play a deterministic role. On the other hand, choosing high bending fatigue strength strip steel for valve leaves could prevent bending fatigue failure. In addition, bending fatigue strength could be examined in commercial fatigue testing devices. In this regard, the parameters, which affect the impact fatigue life, are needed to be investigated in a special impact fatigue testing system.

The influence of surface treatments was investigated by Svenzon (1976) and Soedel (1984). Tumbling and shot peening were stated as the methods of surface treatments. They reported that; on the surface of flapper valve steels, introducing compressive residual stresses and reducing or eliminating the surface defect stress raisers by the surface treatments, significantly improved the bending fatigue strength. Chai *et al.* (2004) emphasized that tumbling or tumbling and shot peening operations as surface treatments, had increased hardness near the surface by plastic deformation and introduced compressive residual stresses that lead higher resistance to fatigue crack initiation.

The automated test system for impact fatigue presented here is a unique test system that enables the investigation of impact fatigue characteristics of thin strip specimens such as compressor valve leaves subjected to repeated impact loads. The system simulates the real working behavior of valve leaves during lifetime.

2. EXPERIMENTAL SET-UP

The test system was designed in such a way that the impact fatigue life characteristics of the compressor valve leaves could be investigated and crack initiation could be detected with the aid of a microphone. Extensive impact fatigue tests were performed in the test system which is schematically shown in Fig. 1. The real working behavior of the valve leaves in the compressor was simulated with a non-contact actuation. The test system included compressor valve plate and fixture, solenoid valve, pressure regulator, filter, pressure sensor, function generator, DC power supply, cycle counter, PC & data acquisition system, microphone, signal input/out (I/O) connector block, transistor circuit, Laser Doppler Vibrometer (LDV) and LCD Screen for CCD camera in LDV.

In the test system, original valve plate and valve leaf couple was utilized through the experimentation in order to simulate the real behavior in the compressor. A fixture was designed to mount the valve plate. The main principle of the system is to create pulsating airflow through a solenoid valve. The pressurized air supplied from the main compressed air source is filtered with a good particle separation and regulated with minimal hysteresis in order to avoid pressure oscillations. The solenoid valve is actuated in the desired frequency by generating reference signals with the aid of function generator in order to simulate the opening and closing movement of the valve leaf. The numbers of impacts are displayed by an electronic cycle counter, which is connected to the function generator. The inlet pressure is measured and displayed by a pressure sensor. When a failure occurs on the specimen due to impact fatigue, the failure detector terminates the experiment. Graphical programming environment was created with LabVIEW software for data acquisition, signal processing and triggering mechanism. The impact fatigue experimental setup provides an automation system for controllable impact fatigue tests.

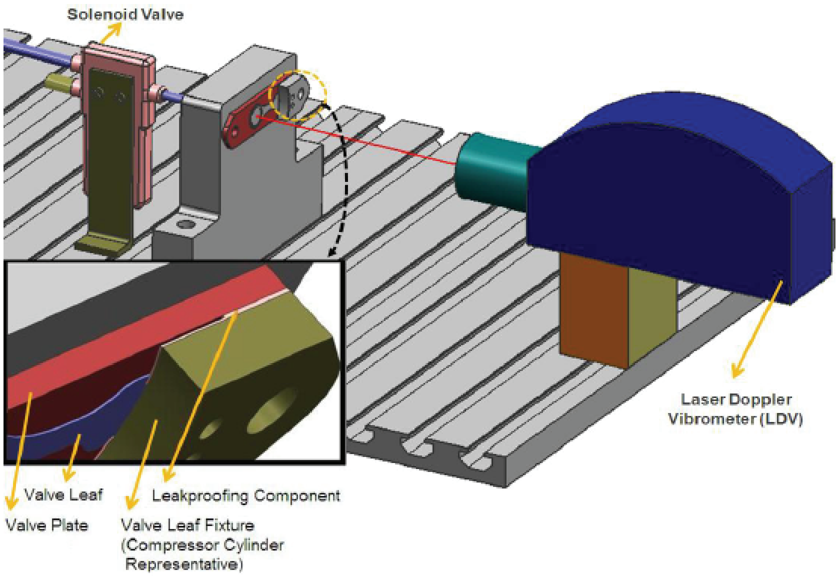

Fig. 1. Schematic display of the test system

3. METHODOLOGY

3.1 Materials

The materials used in the tests were hardened and tempered carbon flapper valve strip steel, a martensitic stainless strip steel and high-grade stainless steel. Chemical composition of the materials are presented in Table 1, and mechanical properties are listed in Table 2. The structure of the specimen is tempered martensite. Grain of material was longitudinal oriented in production. Valve leaves used in hermetic reciprocating compressors for refrigeration were investigated.

Table 1. The chemical composition of strip steels

Material	Chemical composition (nominal) %						
	C	Si	Mn	P	S	Cr	Mo
Carbon Strip Steel	1.00	0.30	0.40	0.008	0.0070	-	-
Stainless Strip Steel	0.38	0.38	0.50	0.018	0.0027	13.45	0.94
High-grade Stainless Strip Steel	0.38	0.35	0.60	0.015	0.0035	13.58	1.01

Table 2. Mechanical properties of strip steels

	Mechanical properties (at 20 °C)	
Material	Min Tensile Strength R_{min} (MPa)	Max Tensile Strength R_{max} (MPa)
Carbon Strip Steel	1990	2030
Stainless Strip Steel	1770	1830
High-grade Stainless Strip Steel	1860	1940

3.2 Experimental Procedure

The experiments were performed at room temperature in dry environment conditions. The impact velocity and displacement of the specimens, which characterize impact fatigue lifetime, were measured simultaneously with LDV. The measurements were performed on the center of the valve leaf impact region. The tests were performed at 250 Hz. When a fracture occurs at the edge of the specimen, the microphone detects the failure. The automated system prevents further damage on the specimen by terminating the test and the impact fatigue life of the specimen is recorded. During the tests, stroboscopic motion of the valve leaves was displayed on the LCD screen with a CCD camera mounted in the LDV.

4. RESULTS AND DISCUSSION

4.1 Edge Radius Effect

After the manufacturing process of the valve leaves, a tumbling operation is performed to clean the burrs and eliminate possible fracture regions at the edges. Tumbling operation provides smooth and rounded edges and removes manufacturing defects that behave like stress raisers. The duration of the tumbling process, which affects edge radius and impact fatigue life of the valve leaves, was investigated for five levels. After the manufacturing process, the edge radius of the specimens was measured on three randomly selected specimens for every level of tumbling duration shown in Fig. 2. Tumbling duration was correlated with the impact fatigue life for carbon strip steel (Fig. 3) and stainless strip steel (Fig. 4).

As it can be seen from Figure 2, the increase of the tumbling duration significantly increases the edge radius up to a certain level for both the carbon and stainless steels. However, after 0.045 to 0.050 mm radius level, further increase in the tumbling duration does not seem to have an important effect on the edge radius.

When the number of cycles to failure of a certain valve geometry is plotted against the tumbling duration at an impact velocity level of 11 m/s (Figure 3), it can be observed that the number of life cycles is improved up to a certain level which shows a similar characteristic to the edge radius – tumbling duration relationship. The same characteristis is also observed for stainless steel at an impact velocity level of 14 m/s (Figure 4).

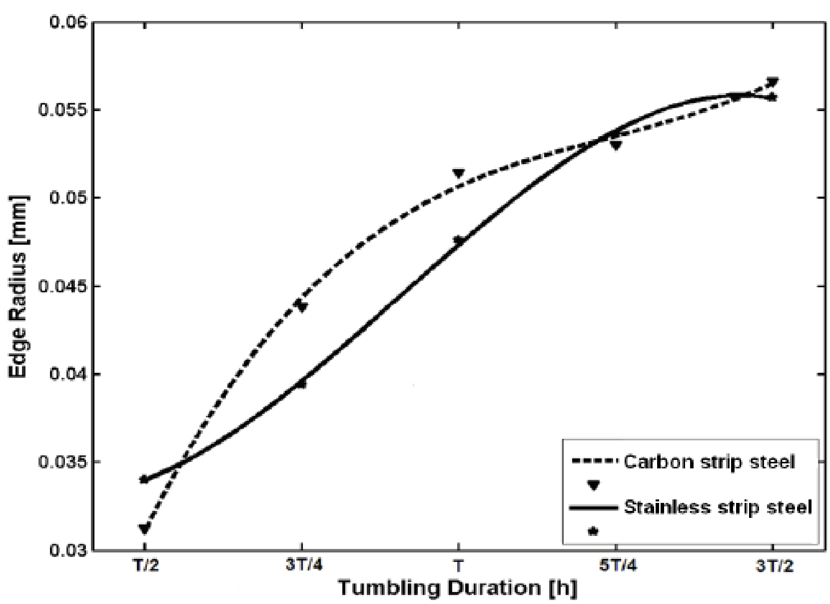

Fig. 2. Effect of the tumbling duration on the edge radius

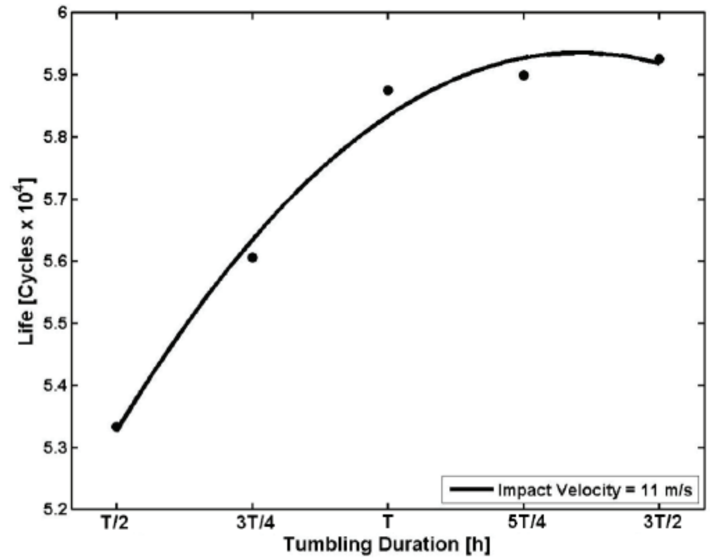

Fig. 3. The effect of tumbling duration on impact fatigue life of carbon strip steel.

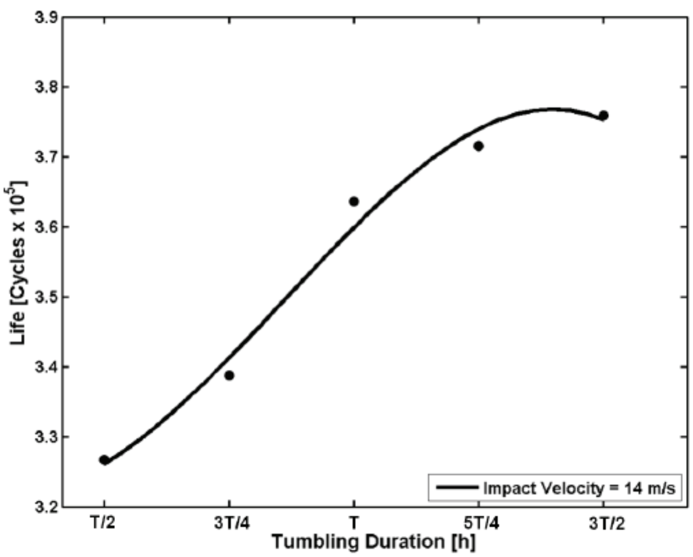

Fig. 4. The effect of tumbling duration on impact fatigue life of stainless strip steel.

4.2 Impact Fatigue Life Comparison

The tests were performed so that the influence of the strip steel used in compressor valve leaves was investigated in terms of impact fatigue life. Three types of materials were tested, carbon strip steel, stainless strip steel and high-grade stainless strip steel. The lifetime of three different strip steel materials were compared at 14 m/s impact velocity for a certain valve leaf geometry and presented in Fig. 5. It can be seen from the figure that stainless strip and high-grade stainless strip steels were superior to carbon strip steel. In addition, stainless strip steel and high-grade stainless strip steel were compared at three different impact velocity levels, at 15 m/s, 14 m/s and 13.5 m/s. High-grade stainless strip steel impact fatigue strength was higher than stainless strip steel. The difference between the lifetimes of the two types of materials decreased as the impact velocity increased. The results are presented in Fig. 6.

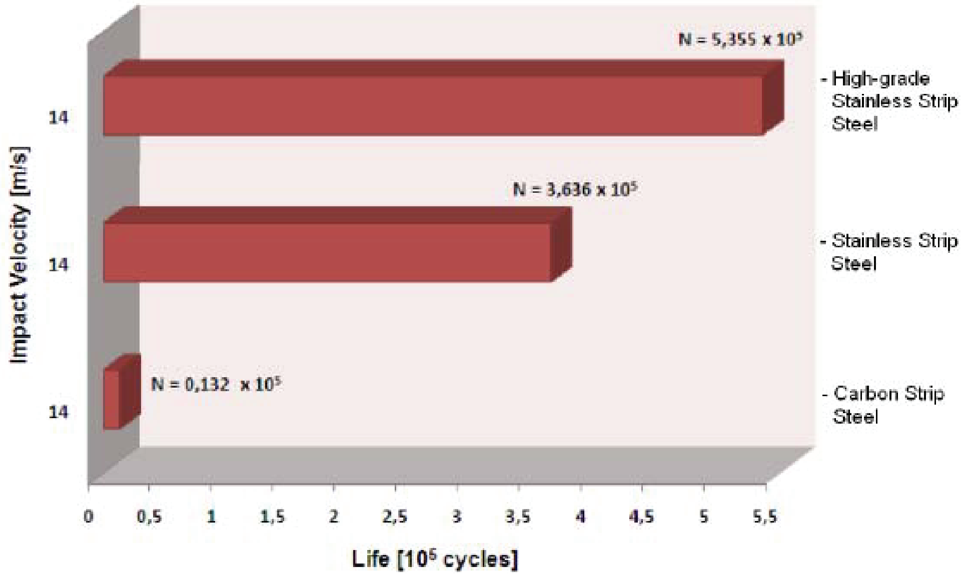

Fig. 5. Comparison of impact fatigue life for 14 m/s impact velocity

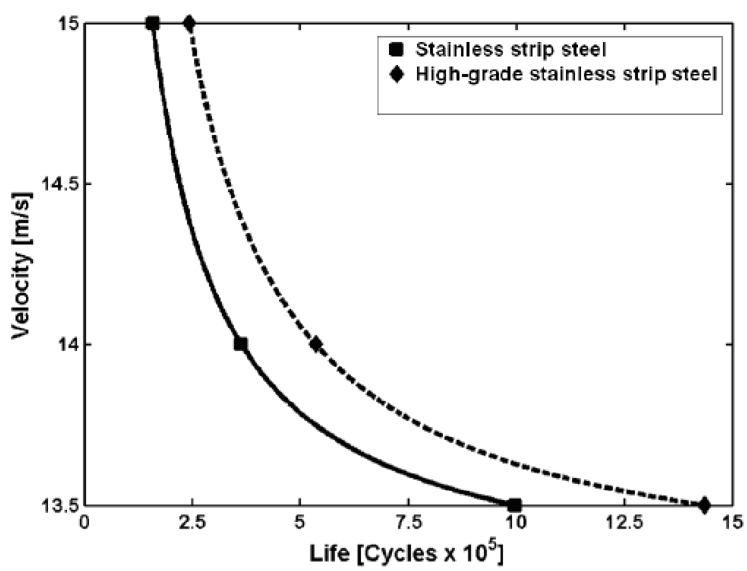

Fig. 6. Comparison of stainless strip steel and high-grade stainless strip steel.

4.3 The Influence of The Operating Temperature

The experiments were performed on the valve leaves around the operation temperature in the compressor and the influence of temperature on the impact fatigue lifetime was investigated. The tests were carried out for carbon strip steel with the original valve leaf design. Various impact velocities were tested at 70, 90 and 110°C and the impact velocities were compared in terms of impact fatigue lifetime shown in Fig. 7. Experiments showed that an increase in the temperature slightly decreased the impact fatigue life in the test temperature range; in addition to that there was no clear difference between the impact fatigue lifetime at 70°C and room temperature.

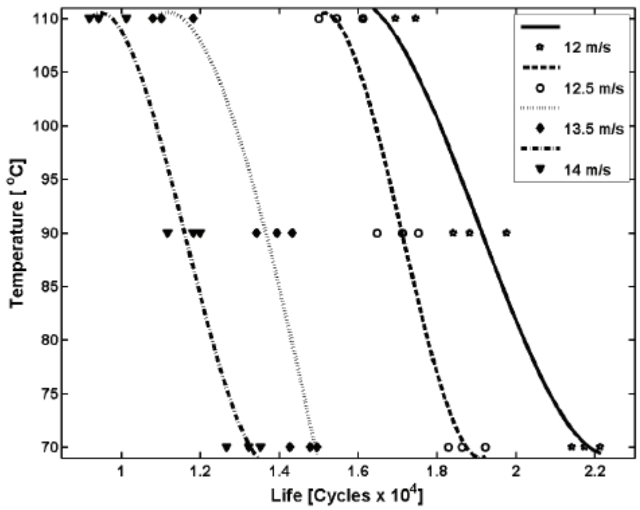

Fig.7. The influence of temperature on the impact fatigue life of carbon strip steel.

5. CONCLUSIONS

In this study a specially designed and constructed valve leaf impact test system is presented. The system utilizes high frequency air pulses to move the valve leaf and the impact velocity is measured with the aid of a Laser Doppler Vibrometer. Various tests were performed on a certain type of valve design where specimens were manufactured from carbon, stainless and high-grade stainless steels. As a result of the tests it can be concluded that:

- Increasing the tumbling duration above a certain process time does not increase the edge radius of the valve leaves. Since the edge radius effects the impact fatigue life time of the valves a similar relationship between the tumbling duration and fatigue life is also observed.
- When carbon steel, stainless steel and high grade stainless steel are compared for the valve design under consideration and an impact velocity of 14 m/s, it is concluded that the life times of stainless and high grade stainless steel are 28 to 40 times longer than that of carbon steel.
- The fatigue life time of the specific design under consideration is almost the same for ambient temperature and 70°C. However further increase in temperature can slightly decrease the fatigue life time on the order of 15% per 20K temperature increase.
- Further research and test results are needed to have a more detailed analysis of the impact fatigue life times of compressor valve leaves. The effect of the geometry and the material of the valve plate can be an interesting future research topic.

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