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ABSTRACT

Although plastic utilization is abundant in the automotive industry and growing day by day, its usage is very limited, especially in the running gear of air conditioning and refrigeration compressors.

In recent years, different polymers have been developed by several manufacturers and the properties of some are suitable for use as a valve material for reciprocating compressors. In Inertia compressors, Kadel suction valves are utilized to attain high efficiency and reliability under wide range of compression ratios. For this reason, the Inertia compressor is very suitable for heat pump air conditioners.

INTRODUCTION

After the Energy Crisis, energy conservation has been the most important topic in the field of air conditioning. In the United states, the regulation of system efficiency started in 1992. Besides the governmental regulations, higher efficiencies have been required from the distributors to meet the customer's needs concerning energy savings.

In such a situation, there came a strong demand for higher efficiency compressors, because the improvement of compressor efficiency is the most economical method to increase unit efficiency in spite of technological difficulties. Thus, most compressor manufacturers have been eagerly improving conventional compressors and developing new ones.

The Inertia compressor is a new generation of reciprocating compressor, utilizing polymer suction and discharge valves.

This paper describes the properties, design, development, testing, and implementation of the polymer suction valves in the Inertia pump, which is one of the highest efficiency reciprocating compressors in the market today.

DESIGN FEATURE

The plastic valve when used dynamically in a compressor, running approximately five million cycles in 24 hours, is very critical and must have the physical and mechanical properties to withstand the cyclic loading, high temperature, impact, and fatigue. High tensile strength (30,000 psi), low elongation (1.5%), high flexural modules (2.3 million psi) and high deflection temperature (634°F) are some of the key properties of the polymer suction valve material. Table 1 shows the characteristics of different polymers that have been evaluated for the Inertia compressors.

Kadel E-1230 (Polyaryletherketone, PAEK) has proven to be the most suitable. The selected high-performance thermoplastic is shown in Table 2. Table 3 compares the strength of different polymers at room temperature. Graphs 1 and 2 depict bending fatigue of Kadel E-1000 at and reverse bending fatigue of Kadel E-1230, respectively.

Availability, pricing, design, molding, and machining are also important factors in the successful application of the suction valves (shown in Fig. 1).

Contrary to the standard practice of "Swedish Flapper Valve Steel" suction valve on a steel valve plate, the polymer suction valves simply rest on the inner and outer seats of the machined cast iron pistons. The retainer screwed into the piston post controls the lift of the suction valve which is optimized to achieve the desired efficiency and sound level of the compressor.

The suction gas is routed directly through the crankcase body into the piston suction ports. The direct gas is much cooler (Fig. 2) and has less pressure drop as it flows through the 360° opening of the suction valve. The result is higher BTU/cubic inch (Fig. 3) and higher efficiency of the pump (Fig. 4).

ENDURANCE TESTING

The different polymer valves have been evaluated to assure the efficiency of the compressor. Also extensive endurance testing of the different valves has been undertaken to select the final polymer, which is 30% carbon reinforced PAEK. Finite element analysis has been used extensively in designing the valve and correlated with the actual performance and life testing. A large database has been constructed. Life testing of Inertia compressors at the different abuse and accelerated conditions is summarized in Table 4.

CONCLUSION

Control of base material (resin pallets) and molding process (humidity, temperature control, melting, feeding, gating, and injection) must be perfected to control porosity, shrinkage, cracking, and other problems during injection molding. Machining to the final dimensioned valves is another milestone. Matching the mating parts, e.g., piston seats and valve contact areas is very critical to the performance. By perfecting these features, the polymer valve has been successfully implemented in the Inertia compressor.

ACKNOWLEDGEMENT

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REFERENCES

[1] High Performance Thermoplastic Resins and their Composites, Sylvie B'eland.

[2] 39th SPIRP/C Conference, ASTM D-671.

Polymer Characteristics

Characteristic	Thermid MC6000	Vespel SPI "M"	Peek 450G	Ultem 6000	Torlon 4203L	Shamban 17445	Kadel E1230
Tensile strength(psi) at 73° F	12,000	12,500	14,500	15,000	22,000	31,000	30,000
Elongation at break (%)	2	7.5	35	30	15	2	1.5
Flexural modulus (psi) at 73° F	650,000	450,000	550,000	440,000	730,000	2,600,000	2,300,000
Poisson's ratio	—	0.41	0.42	—	0.38	—	0.32
Deflection temp.(°F) at 264 psi	—	680	320	420	532	554	634
Density (lbs/in3)	0.049	0.052	0.048	0.047	0.051	0.051	0 052
Water absorption after 24 hrs.	0	0.24	0.15	0.28	0.33	0.06	0.02
Hardness	91 Shore D	45-58 RWE 92-102 RWM	—	110RWM	86RWE	110RWM	—
Fatigue endurance (psi) at 10(7) and 73°F	—	6,000	11,500	—	6,000	—	12,000
Fatigue endurance (psi) at 10(7) and 275°F	—	4,000	—	—	2,400	—	7,000
Fristion coef. @ PV-25000	0.21	0.29	0.15	—	0.33	—	0.20
Isod impact : Notched	—	1.5	1.6	—	2.7	1.1	1.5
Ft-lb/in: Un-notched	—	30	no break	—	20	11	11.2
Type Material	Polyimide	Polyimide (machined)	Polyether-etherketone	Polyethe-rimide	Polyamide-imide	Carbon re-inforced polyether-etherketone	30% carbon reinforced PAEK (polyaryl-etherketone)

Table 1

TABLE 2 Selected High-Performance Thermoplastics

GENERIC NAME	MANUFACTURER	TRADE NAME
POLYKETONES		
Polyetheretherketone (PEEK)	Imperial Chemical Industries (ICI)	Victrex PEEK
Polyetherketone (PEK)	Imperial Chemical Industries (ICI)	Victrex PEK
Polyetherketoneketone (PEKK)	E I Dupont de Nemours	PEKK (1)
Polyetherketoneetherketoneketone (PEKEKK)	BASF	Ultrapek
Polyketone	Amoco Performance Products	Kadel
POLYARYLENE SULFIDES		
Polyphenylene sulfide (PPS)	Phillips Petroleum Company	Ryton PPS
Polyarylene sulfide (PAS)	Phillips Petroleum Company	Ryton PAS-2 (2)
Polyphenylene sulfide sulfone (PPSS)	Phillips Petroleum Company	Ryton S PPSS (2)
POLYAMIDES		
Polyamide	E I Dupont de Nemours	J 2 (1,2)
Polyamideimide (PAI)	Amoco Performance Products	Torlon
POLYIMIDES		
Polyaryleneimide	E.I Dupont de Nemours	K-Polymer
Polyaryleneimide	E.I Dupont de Nemours	N-Polymer
Polyimide	Ethyl Corporation	EYMYD
Polyetherimide (PEI)	General Electric Company	Ultem
Polyetherimide	American Cyanamid	Cypac
Polyketoimide	Mitsui Toatsu Chemicals Inc. (MTC)	Larc-TPI, New-TPI
Polyketoimide	Rogers Corp	Durimid

(1) Is or will be available only as custom finished composite material parts
(2) Not commercially available but nearly
(3) Not expected to be commercially available as a matrix for composite material

TABLE 3

Fatigue Strength of Reinforced Engineering Thermoplastics
(data from 39th SPI RP/C Conference, ASTM D-671)
(Room Temperature @ 1,800 cycles/min)

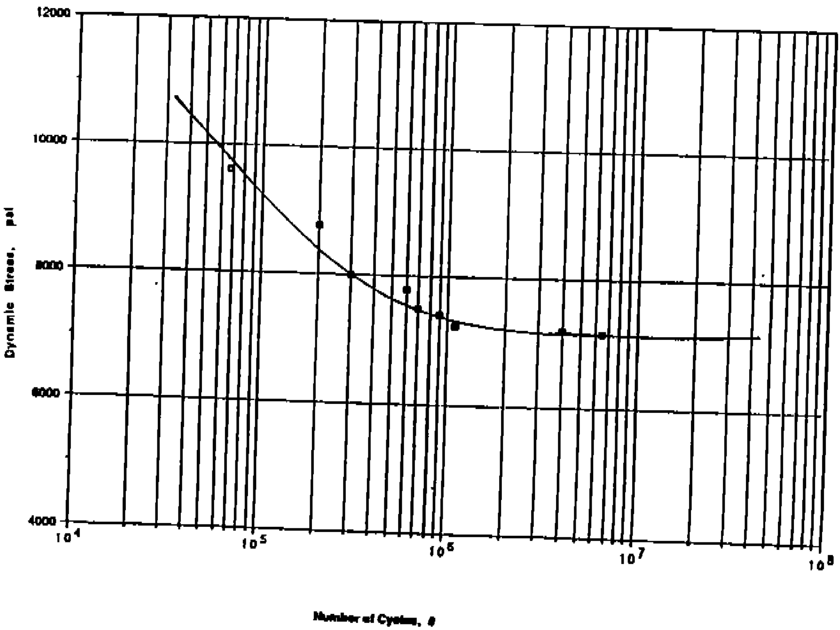
MATERIAL	GLASS FIBER, %	CARBON FIBER, %	STRENGTH, PSI @10^6 CYCLES	STRENGTH, PSI @10^7 CYCLES
Nylon 6/6	--	--	3,400	3,100
Nylon 6/6	30	--	8,000	5,900
Nylon 6/6	--	30	13,000	8,000
PAEK	--	30	18,000	17,000
Polyethersulfone	30	--	16,000	5,000
Polyethersulfone	--	30	22,000	6,700
Polyphenylene Sulfide	--	30	13,000	9,500

Graph 1 shows the fatigue resistance of neat KADEL E-1000 at room temperature with the testing being done by Fatigue Dynamics using bending fatigue at ~30 Hertz.

In consideration, based on the chemistry and type of reinforcement used in KADEL E-1230, a more severe reverse bending fatigue test was conducted on this product by Fatigue Dynamics. This test has the specimen going through two opposed bends during the same cycle speed of ~30 Hertz. To enhance the testing, the data expressed by Graph 2 was conducted at 250°F, just below the Tg of the base resin which occurs at ~300°F. Testing was done at 350F using these same conditions and it was found that ~7,000 psi stress yielded <100,000 cycles to failure and that ~5,300 psi (which was the same applied strain as 7,000 psi stress at 250F) yielded ~200,000 cycles to failure.

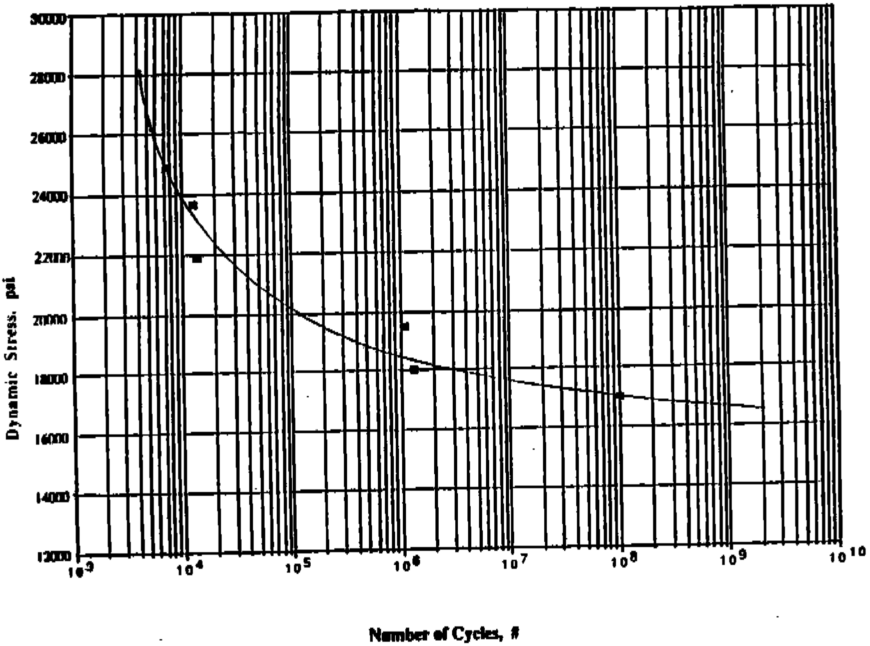
KADEL materials demonstrate superior performance to bending fatigue. Combined with their inherent chemical resistance and superior mechanical and thermal properties, they lead the field of high performance thermoplastics for demanding industrial applications.

"S/N DATA", KADEL E-1000 neat **Graph 1**



Graph 2

"S/N DATA" , KADEL E-1230



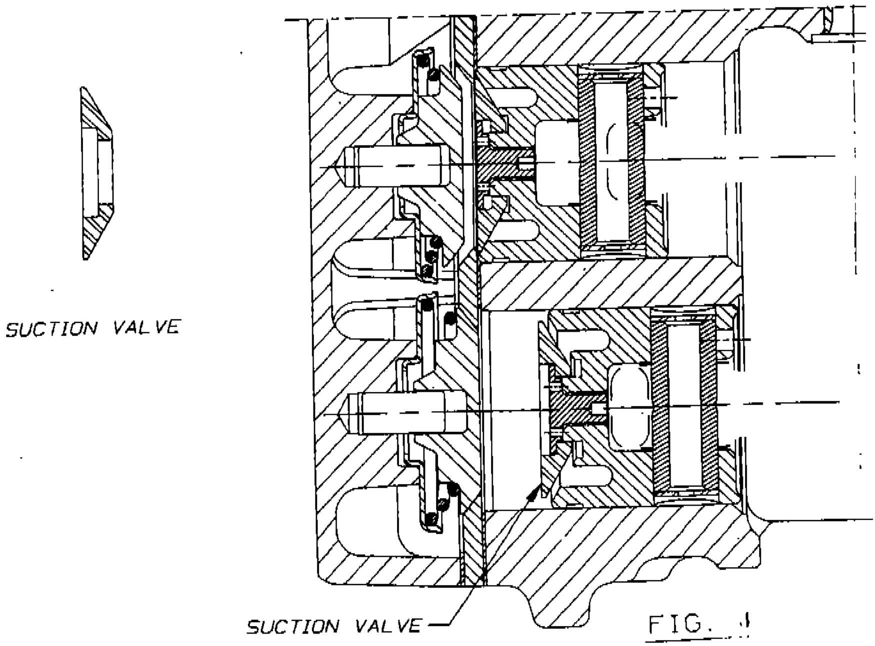


FIG. 4

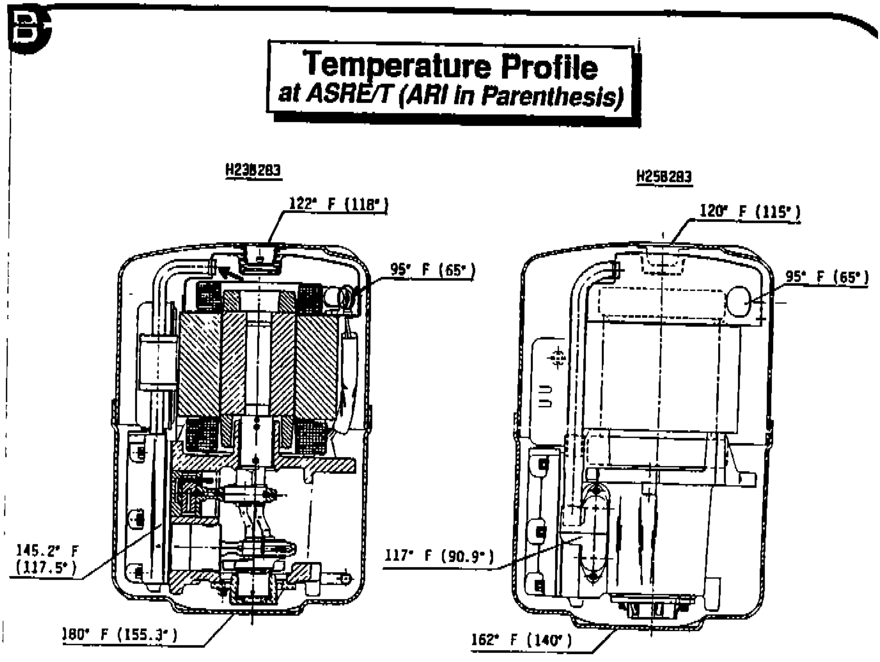


Fig. 2

Bristol Compressors

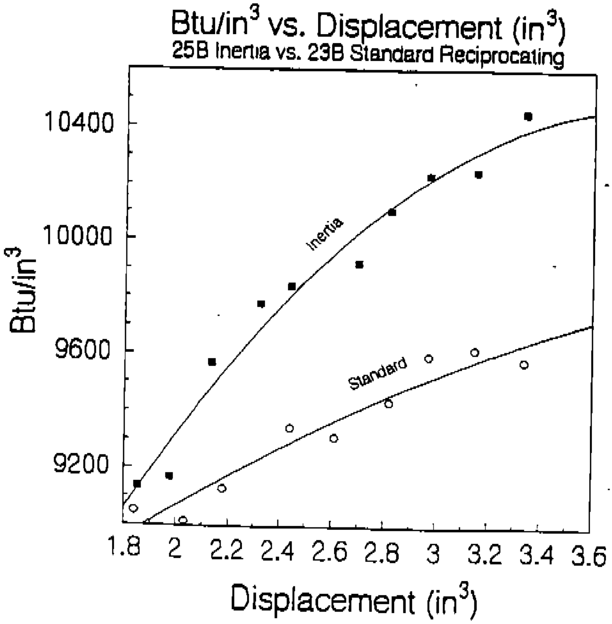


Fig. 3

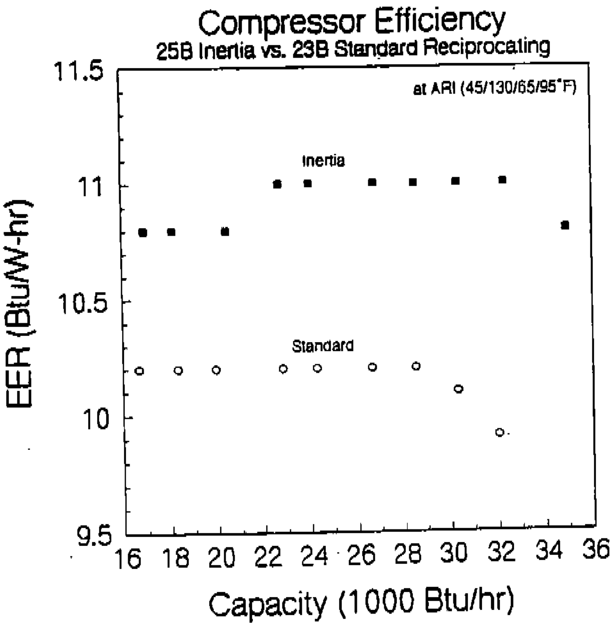


Fig. 4

H25B Life Test Summary

Test Completed	*Completed Life Tests* Number of Compressors
•Standard Slug	26
•Start/Stop	38
•High Compression	19
•Defrost Cycle	14
•Continuous Frostback	9
•High Load	26
•High Mass Flow	6
•Heat Pump	21
•Unitary Slug Test	9
•Continuous Run	2
Grand Total	170

Table 4