This is to certify that the

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PERFORMANCE COMPARISON OF PLASTIC AND WOOD PALLETS
FOR STATIC AND DYNAMIC TESTS

presented by

GARY SINGH GREWAL

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Major professor
S. PAUL SINGH, PH.D.

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PERFORMANCE COMPARISON OF PLASTIC AND WOOD PALLETS FOR STATIC AND DYNAMIC TESTS

Gary Singh Grewal

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ABSTRACT

This study investigated the effect of compression, vibration, drops, and fork truck impacts on seven different types of pallets. These consisted of five plastic and two wood types of pallets. The various pallets tested in this study were:

Structural Foam - HDPE Plastic, 22 lbs.

Twin Sheet Thermoformed (DC3) - HDPE Plastic, 20 lbs.

Twin Sheet Thermoformed (Weightlifter) - HDPE Plastic, 31 lbs.

Single Sheet Vacuum Formed - HDPE Plastic, 18 lbs.

Injection Molded - HDPE Plastic, 55 lbs.

Stringer and Deckboard Nailed - Wood, 47 lbs.

Block and Deckboard Nailed - Wood, 60 lbs.

The pallets were subjected to various test methods to compare the relative performance of pallets fabricated from different materials to a specified performance criteria. The test methods determine the relative resistance of pallets to deformation, damages, and structural failures which detrimentally affect the functionality of the unit load. The pallets were inspected for damage after the tests. A failure criteria was developed to evaluate the performance of the various pallets after completion of all tests. The study concluded that plastic pallets performed better than wooden pallets. Among the plastic pallets tested the Twin Sheet Thermoformed Pallet (31 lbs.) and the Injection Molded (55 lbs.) pallet showed the best performance. The block style wood pallet showed better performance than stringer style wood pallets.

This thesis is dedicated to my parents

for all the love and support they have provided.

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to my major professor, Dr. S. Paul Singh for his assistance, guidance and support throughout my graduate study and research.

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In addition I want to thank my wife Bridget, and my daughters Chantel and Nicole for all the support and love they provided during my graduate studies.

Finally, I would like to thank all my colleagues who helped me and encouraged me during my research project, and the Consortium of Distribution Packaging for the funding for this study.

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1.0 INTRODUCTION

A pallet is a fabricated platform used as a base for assembling, storing, handling and transporting materials and products in a unit load. Pallets were introduced as a materials handling tool in the 1930's after the fork truck manufacturers developed small highly maneuverable lift trucks and hand jacks. In 1946, the food processing industry, together with transportation companies, terminal warehouse companies, and the pallet manufacturing industry, recommended the adoption of 48 x 40 inch and 40 x 32 inch pallet sizes. Pallet size is defined by the dimensional length and width of the top deck.

Pallets are the basic component of today's material handling and are one of the most efficient and effective ways to handle goods and materials as unit loads. Serving as a platform base for stacking individual items, pallets offer a number of advantages (Wiley, 1986):

a. Pallets permit the handling of larger loads sharply reduce loading and unloading times, and streamline the flow of materials.

b. They form an efficient package that is compatible with land, sea, and air carriers.

c. They move easily over conveyors and into automatic palletizers.

d. Their unique nature makes them suitable for rapid movement by a variety of mechanical equipment such as conventional fork lifts, hand pallet jacks, overhead cranes, and slings.

The most common pallet sizes in the United States are 48 x 40 in. and 42 x 42 in. which are generally used by the grocery industry, because of their easy use across railroad freight cars and the average truck body. Table 1 shows that 43.8 % of pallets sold in the U.S. market includes a variety of sizes each representing under 1% of total production (NWPCA, 1981). This accounts for the fact that there are literally thousands of pallet size classifications and designs. In Europe the two most common sizes of pallets are the 1000 x 800 mm and 1200 x 1000 mm.

1.1 PALLET TYPES.

Ninety percent of all pallets sold are wooden stick built units. The remaining 10% of the market is comprised of Plastic, Aluminum, Steel, Foam, Corrugated Fiberboard, and Molded wood. Wood pallets represent the majority of pallets types sold each year. The National Wooden Pallet and Container Association (NWPCA) reports that U.S. industries purchased over 504 million new wood pallets in 1990 (Witt, 1990). Wood pallets come in a variety of sizes and can be designed to meet the requirements of a wide range of applications.

1.1.1 Wood Pallets.

Wood pallets are constructed of one or two deckboards secured to deck spacers, which may be either stringers or blocks. Figure 1 represents a stringer type pallet and Figure 2 shows the block type pallet. The deckboards are

TABLE 1: Percent Production of Pallet Sizes in the United States

SIZES	PERCENT OF TOTAL PRODUCTION
48 " x 40"	28.5
42" x 42"	5.4
40" x 48"	4.8
48" x 48"	4.2
48" x 42"	3.2
40" x 40"	2.9
36" x 48"	2.4
36" x 36"	2.2
48" x 36"	1.3
44" x 44"	1.3
All Other	43.8
Total	100

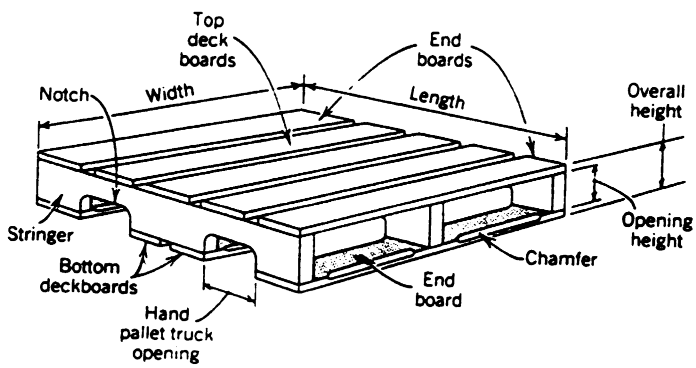

Figure 1: Stringer Style Wood Pallet.

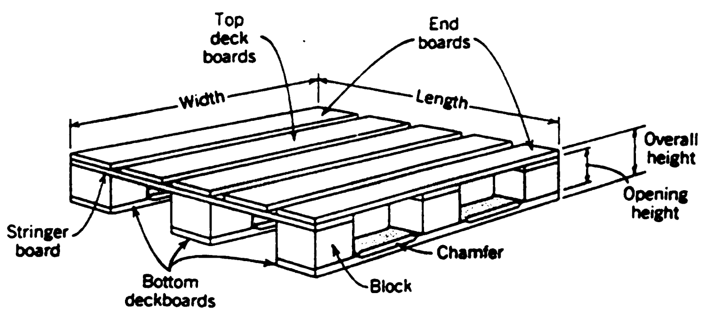

Figure 2: Block Style Wood Pallet.

structural members that make up the faces of pallet. These are two, top and bottom deckboards. The top deck is the surface that carries the load. The bottom deck is the surface that helps distribute the load when pallet is placed on top of another load. Reversible pallets have similar top and bottom decks capable of carrying the load. Non-reversible pallets have dissimilar top and bottom decks with only the top deck capable of carrying a load. Wood pallets have a chamfer which is a beveled edge on the top side of end board for purpose of easy entry and exit of fork lifts. Chamfers are also required on the underside of the top deckboards on reversible pallets. The stringers are wood runners and structural members to which deckboards are fastened. A notched stringer is a stringer that has openings cut out for insertion and withdrawal of forks of a fork truck. However pallet jacks can enter only from two directions.

Two way entry pallets have a solid stringer so that fork truck can enter the pallet only from two ends of a pallet. Four way entry pallets are block type so that the fork truck can enter the pallet from any four directions. The cost of wood pallets range anywhere from $ 4.00 - $ 25.00 depending on the requirements of application, dimensions, load carrying capacity, wood quality and manufacturing process.

The weight of wood pallets ranges between 40 to 100 lbs. Typical applications include the grocery, automotive, durable goods and hardware products.

1.1.2 Corrugated Fiberboard.

Corrugated Fiberboard pallets are light weight alternatives to wooden pallets suitable for uniform loads. The pallets are popular as in store displays. These pallets are significantly lighter than wood for comparable performance, and have no nails or splinters to damage products. Corrugated Fiberboard pallets weigh approximately 10 lbs. and can support uniform dynamic loads up to 5600 lbs. and static loads of 15000 lbs. A recent test project at Michigan State University show that Stone Containers Core-Deck pallets could withstand 5600 lbs of dynamic vibration load. Most paper based pallets are recycled. Limitations are their performance is affected by high humidity and long term storage (creep) and are not suitable for outside storage. They do not offer racking abilities.

Corrugated pallets are an economical option for a one way shipping pallet with a price range of $ 3.00 - $ 7.00. The base weight ranges from 8 to 12 lbs. Typical applications include the grocery, light weight paper products, and the automotive industry for light weight products.

1.1.3 Pressed wood fiber.

A space saving alternative to the conventional wood pallet is the molded pressed wood fiber pallet which is nestable. Molded from a mixture of wood fiber and synthetic organic resins, pressed wood pallets offer a four-to-one nesting ratio for storage or return shipping. With a smooth solid deck these nail free pallets also help minimize the potential for product damage.

Pressed wood fiber pallet cost ranges between $ 4.75 - $ 7.00. The base weight ranges between 30 to 42 lbs. Typical applications include the United States Postal Service for bulk bags, order picking, printed materials, and building materials. However there are some problems associated with the disposal of these pallets since they cannot be repaired of recycled.

1.1.4 Plastic.

Plastic pallets are either single faced as shown in Figure 3 or double faced as shown in Figure 4. Double faced pallets have closed top and bottom deck or perforated top and bottom deck or a combination of both. Single faced pallets may also be closed deck or perforated. Almost all plastic pallets are accessible from all four directions. Hollow feet in case of single faced pallets allow for nesting. Raised ridges and patterns in both single and double faced pallets with similar pattern on the bottom of containers allows for interlocking.

Plastic pallets offer several features listed below (Auguston, 1990).

a. Nestable characteristic allows for space saving in warehouse storage and transportation and savings on return shipping.

b. Non absorbent surface offers easy clean surface, and will not initiate bacteria growth.

c. They can be sanitized to meet FDA and USDA requirements for pharmaceutical, food, and chemical applications.

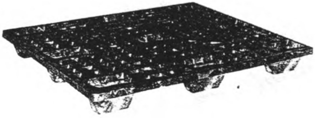

Figure 3: Single Faced Plastic Pallet.

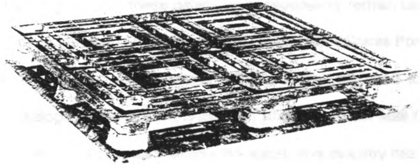

Figure 4: Double Faced Plastic Pallet.

d. No nails or splinters minimize product damage and improve manual handling safety.

e. Compatible with pallet conveyance equipment, and automated handling systems.

f. Inter-stacking allows for different size pallets to interlock reducing product damage due to load shift.

g. Plastic pallets last longer in distribution cycle.

Plastic pallets and metal pallets are long lasting alternatives to wood pallets. Despite their high initial cost these pallets typically pay for themselves over a long life. Due to their higher cost, these pallets must necessarily remain captive either in warehouse or closed loop shipping systems. The United States Postal Service is the single largest procurer of plastic pallets. These are used to ship mail (magazines, catalogs, mailers) from publishing houses to Bulk Mail Centers for faster mail processing. In the last decade the automotive industry has developed standard plastic pallets that interface with the returnable containers used to ship parts to assembly plants in a closed loop shipping system.

Plastic pallets are built using several different processing techniques which include Structural Foam Molding, Injection Molding, Rotational Molding, Thermoforming, and Reaction Injection Molding. The structural foam pallet is built using a low pressure injection molding process which produces parts with a solid skin surrounding a foamed core. Plastic pallets requiring heavy wall sections can be economically produced. The structural foam process requires short cycle times. The pallets have good impact resistance and good deflection strength. Complex shapes can be molded because the process offers good weight and dimensional tolerance. One disadvantage is the high cost of tooling and processing equipment (Wiley, 1986).

The twin-sheet thermoformed pallet is made using a thermoplastic sheet by a sequence of heating, shaping, cooling, and trimming. The twin-sheet thermoforming involves two sheets which are heated and formed in upper and lower molds simultaneously. Then they are fused together by applying pressure to the mating surface. Twin-sheet thermoformed pallets are hollow inside. This is achieved by using a specially designed pin between the two sheets to blow air prior to the fusion process.

The single sheet vacuum formed pallet involves a male mold in which the plastic sheet is clamped and heated to the required forming temperature. Then the sheet is sealed over the male mold and vacuum is applied from beneath the mold, forcing the sheet over the male mold and forming the pallet. The advantages of this process are low cost tooling and low cost equipment. The disadvantage is relatively long cycle times, limited wall thickness and limited design complexity.

The injection molded pallet involves feeding plastic resin to a rotating screw in a heated barrel. There the plastic is melted and mixed. The resulting hot plastic is then injected at high pressure into a closed mold. The mold is cooled and the part is ejected. The process allows production of light weight as well as heavy duty pallets. It allows for complex geometry. The disadvantages are high tooling, equipment, and energy costs.

Most of the plastic pallets are manufactured from High Density Polyethylene (HDPE). Materials like Polystyrene and Polypropylene are used occasionally. HDPE is used because of several reasons listed below (Wiley, 1986).

a. It is readily available and has a wide acceptance due to uniform performance and low cost.
b. Has excellent impact resistance.
c. Outstanding chemical resistance to most acids and bases.
d. USDA and FDA clearance for use in food and pharmaceutical plants.
e. Good performance under a wide temperature range.
f. Offers molding and design flexibility.

One limitation is its inability to resist deflection under load. This deflection problem is more pronounced in pallet racking applications. In racks lacking center supports or decking the pallets must support and maintain load over the open space. With loads exceeding 2000 lbs. plastic pallets without any reinforcements are likely to bend. Over time the plastic pallet will bend to such an extent that it may become difficult to reenter the pallet with the forks of forklift. Pallet design and the method of construction greatly influence pallet performance, price, and acceptance.

Plastic pallets are recyclable and are used to make plastic pallets and other plastic products. Manufacturers are using only a fraction of regrind due to contamination problems. Manufacturers of plastic pallets, totes containers, supplying to the automotive industry have established a recycling program. Rather than pay a disposal fee, customers sell pallets and containers that are no longer usable back to manufacturers for up to 25 % of the original cost. The manufacturer sends the pallets/containers to a recycling plant, which disassembles and grinds them into small bits. The ground up plastic is then used for processing into usable plastic products.

Plastic pallets range in cost between $ 20.00 - $ 80.00. The base weight ranges between 20 to 75 lbs. Typical applications include captive or closed loop systems, food and pharmaceutical, FDA/USDA requirements, and the automotive industry.

1.1.5 Metal.

Steel and aluminum pallets are highly durable. Some steel pallet manufacturers offer a ten year warranty. Metal pallets can be sanitized to meet FDA and USDA requirements for pharmaceutical, food processing and chemical applications. Even though the pallets cost more than wood pallets, they often pay for themselves in closed-loop applications in less than a year. Metals in general are easy to recycle and typically have a higher salvage value.

The cost of metal pallets ranges between $ 30 - $ 350. The base weight ranges between 30 to 100 lbs. Typical applications include FDA / USDA applications, defense, heavy equipment, and aerospace industries in captive systems.

1.2 POOLING.

Since World War II when U.S. Armed Forces simply abandoned their surplus pallets on foreign shores, the pallet industry has sought better methods of disposal. Despite the popularity of wood pallets some users have raised concerns over their disposal. In some areas of the country, it now costs almost as much to dispose of a wood pallet as it did to buy it in the first place. Compounding the disposal problem is the large number of pallets used for one way shipping applications.

The problem stems from the current pallet exchange system, in which shippers and receivers "voluntarily" exchange pallets of supposedly similar quality on a unit for unit basis. When a company ships goods to its customers on pallets, it expects to get back the same number, in similar condition. Unfortunately, this has been difficult to manage in initial attempts. To encourage use of higher quality wood pallets that stay in the system longer, many companies are exploring a more formalized approach to pallet exchange, called pallet pooling. A pallet pool consists of a network of cooperative locations that receive, exchange, and transfer pallets. Participants rent or lease these pallets from a third party that manages some or all transactions. Pool participants benefit in a number of ways (Auguston, 1991).

a. The pool uses a standard pallet, and pallet quality is consistent throughout the system.

b. Rental fees include the cost of routine maintenance, helping to keep bad pallets out of circulation.

c. Higher quality pallets reduces repair and eventually generates less waste.

d. Pooling system ensures no cheating, and that pallet exchange is equitable for all parties involved.

e. Significant cost savings.

The major national companies that offer these services are briefly described in this section. The National Pallet Leasing Systems, Inc. is the oldest third party pallet management company in the U.S. Some 40 companies, participate in the company's Pallet Exchange Program. NPLS moves an estimated $2 billion worth of unitized product among some 900 locations coast-to-coast. The Mid South Industrial Sales, Fort Smith, Arkansas based company started its first pallet management program in 1985. Today, Mid South has pallet recovery facilities in 13 locations and four full service terminals. CHEP USA is a joint venture of GKN and Brambles Enterprises, Ltd. CHEP USA's National Pallet Pool was launched in September, 1990. Initially it focused its efforts on the grocery industry, CHEP has a network of 106 pallet supply depots and regional servi+w centers. The First National Pallet Rental, Inc. is currently operating several pallet manufacture and repair depots in the Midwest. It was recently acquired by Menasha Corporation. Major grocery manufacturers, and several distributors participate in this program.

1.3 STUDY OBJECTIVE.

The purpose of this study was to compare various types of plastic and wood pallets. The study determined the performance of these pallets to various types of static and dynamic forces. In addition the pallets were subjected to a series of repetitive warehouse life cycles to determine the effect of multiple uses. The various tests performed on the pallets were,

1. Stiffness and Flexural Strength
2. Vibration Testing of Pallet Loads
3. Lateral Stability and Diagonal Rigidity of the Pallet due to Drops
4. Impact Test of Leading Edge, Blocks and Posts
5. Slue resistance and Abrasion to Feet due to Fork Truck Handling

The tests were performed using recommended test procedures and severity levels as indicated in the appropriate ASTM standards and test methods developed by Michigan State University. These methods provide a uniform basis to compare and evaluate pallet structures made from different materials and designs to the expected hazards found in the distribution environment during shipping and handling of palletized loads.

2.0 EXPERIMENTAL DESIGN

In this study, seven different types of pallets were tested. All pallets were inspected prior to testing at the School of Packaging test labs. The pallets were preconditioned at 72°F and 50% Relative Humidity for at least 24 hours prior to test. The various pallets tested were designated an alpha code described below since some had similar manufacturing process but varied in design and weight.

2.1 PALLET TYPES.

The various pallets tested in this study were:

A Structural Foam - Plastic

B Twin Sheet Thermoformed (DC3) - Plastic

C Twin Sheet Thermoformed (Weightlifter) - Plastic

D Single Sheet Vacuum Formed - Plastic

E Injection Molded - Plastic

F Stringer and Deckboard Nailed - Wood

G Block and Deckboard Nailed - Wood

Figures 5 to 18 show the top and bottom views of all pallets tested and are provided at the end of this chapter. The size, weight, material, and process of each pallet is briefly discussed in the following section.

2.1.1 PALLET A.

This 48 x 40 inch structural foam HDPE plastic pallet as illustrated in Figure

5 (Top View) is a single faced pallet with a perforated top deck. The pallet is accessible from all four directions by a fork truck. The top deck surface is smooth. It has a 0.5 inch lip all the way around. The pallet has eight feet to carry the load as illustrated in Figure 6 (Bottom View). Feet are hollow to allow the pallets to be nested. The feet also have their bottoms cut out to save material and to drain out water if pallets are stored outside. The pallet weighed 22 lbs.

2.1.2 PALLET B.

This 48 x 48 inch twin-sheet thermoformed HDPE plastic pallet as illustrated in Figure 7 (Top View) is a single faced with a solid top deck. The top deck surface is smooth. The pallet is accessible from all four directions by a fork truck. The pallet has nine feet as illustrated in the Figure 8 (Bottom View). feet are hollow to allow the pallet to be nested. The pallet weighed 20 lbs.

2.1.3 PALLET C.

This 48 x 40 inch twin-sheet thermoformed HDPE plastic pallet as illustrated in Figure 9 (Top View) is a single faced with a solid top deck. The top deck surface is smooth with no raised ridges. The pallet is accessible from all four directions by a fork truck. The pallet has nine feet as illustrated in Figure 10 (Bottom View). Feet are hollow to allow the pallet to be nested. The pallet weighed 31 lbs.

2.1.4 PALLET D.

This 48 x 40 inch single-sheet vacuum formed HDPE plastic pallet as illustrated in Figure 11 (Top View) is a single faced with solid top deck. The top deck surface is smooth. The pallet is accessible from all four directions by a fork truck. It has a 1.5 inch lip all the way around. The pallet has nine feet as illustrated in Figure 12 (Bottom View). Feet are hollow to allow the pallet to be nested. The feet are staggered for the pallet to interlock with similar pallets and has found great acceptance in the automotive industry. The pallet weighed 18 lbs.

2.1.5 PALLET E.

This 48 x 40 inch injection molded HDPE plastic pallet as illustrated in Figure 13 (Top View) is a double faced with stringers on the top deck. The top deck surface has smooth surfaces. The pallet is non reversible so the load bearing surface is only the top deck. This pallet has a unique feature where it can be snapped together and is therefore economical to repair by simply replacing a damaged stringer or deckboard. The pallet is accessible from all four directions by a fork truck. The pallet cannot be nested since it has no feet as illustrated in Figure 14 (bottom View). The pallet weighs 55 lbs.

2.1.6 PALLET F.

This 48 x 40 inch wood pallet is a stringer type pallet as illustrated in Figure 15 (Top View). The deck boards are nailed to the stringers. The stringers are notched allowing for a four way entry. It is a non reversible pallet as illustrated in Figure 16 (Bottom View). Only the top deck is capable of carrying the load. The pallet weighed 47 lbs. This pallet was manufacture to the Grocery Manufactures Association (GMA) Specification for pallets.

2.1.7 PALLET G.

This 48 x 40 inch wood pallet is a block type pallet as illustrated in Figure 17 (Top View). The deck boards are nailed to the blocks, which allow for a four way entry. This is a non reversible pallet as illustrated in Figure 18 (Bottom View). Only the top deck is capable of carrying a load. The pallet weighed 60 lbs. This pallet was obtained from a local grocery supermarket and is used for pallet pooling.

All the pallets described in the previous pages are shown in Figures 5 to 18 are shown in the following pages.

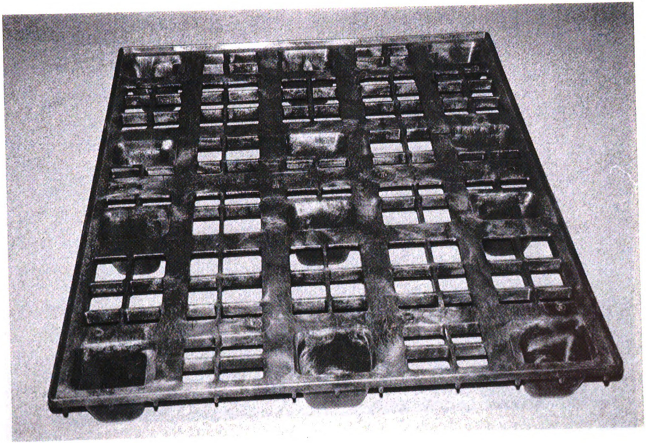

Figure 5. Structural Foam Plastic Pallet (Top View)

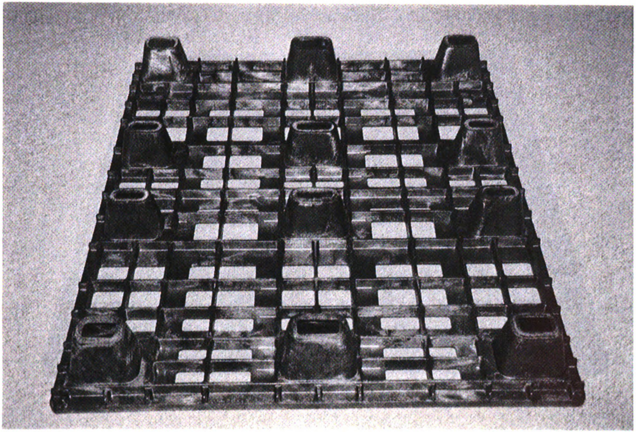

Figure 6. Structural Foam Plastic Pallet (Bottom View)

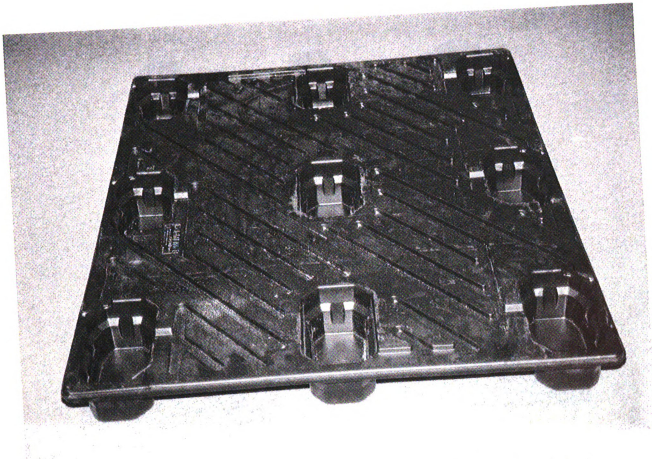

Figure 7. Twin-Sheet Thermoformed (DC-3) Plastic Pallet (Top View)

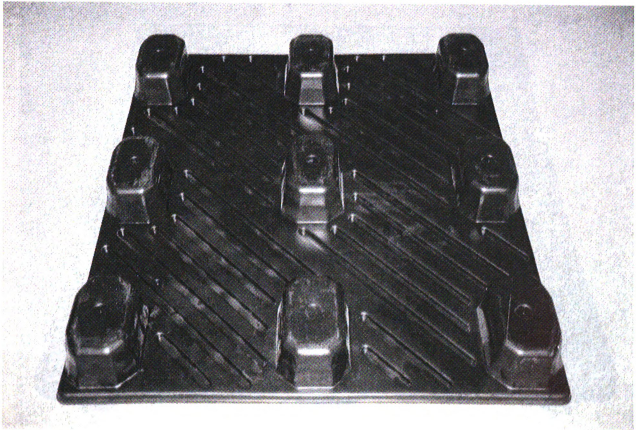

Figure 8. Twin-Sheet Thermoformed (DC-3) Plastic Pallet (Bottom View)

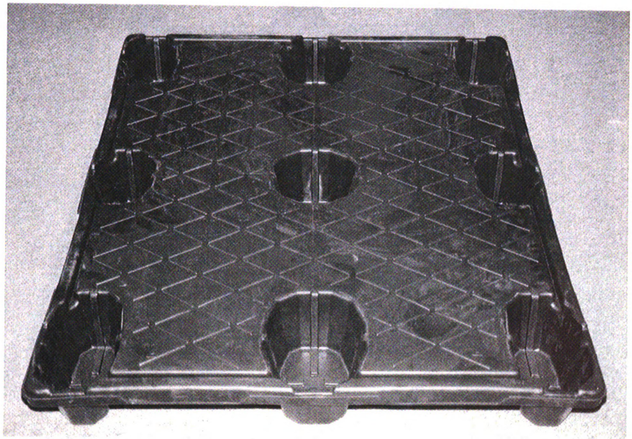

Figure 9. Twin-Sheet Thermoformed (Weightlifter) Plastic Pallet (Top View)

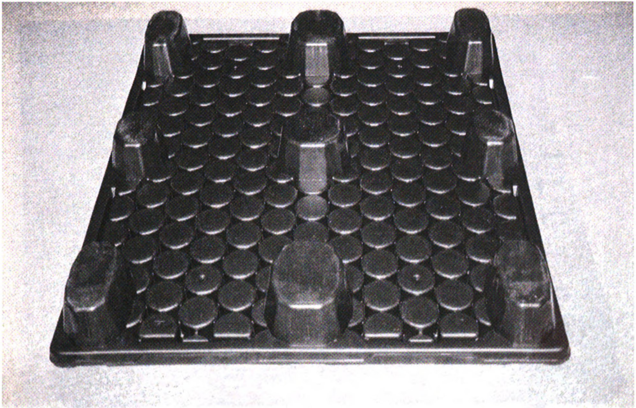

Figure 10. Twin-Sheet Thermoformed (Weightlifter) Plastic Pallet (Bottom View)

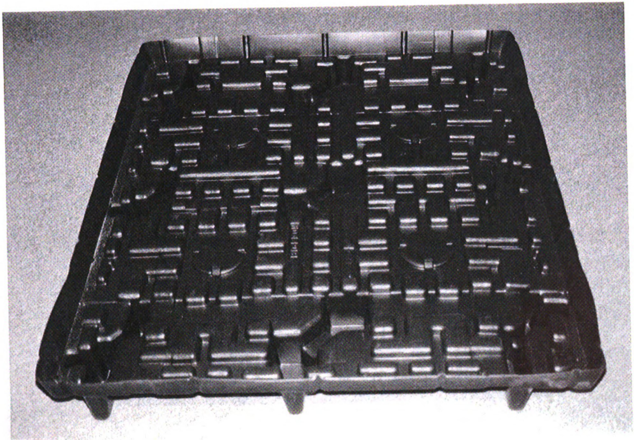

Figure 11. Single-Sheet Vacuum Formed Plastic Pallet (Top View)

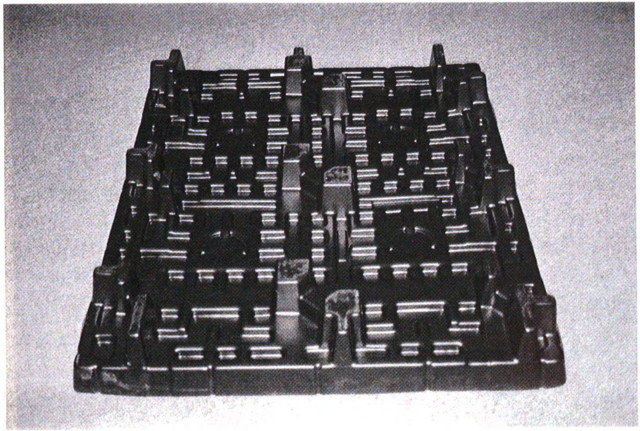

Figure 12. Single-Sheet Vacuum Formed Plastic Pallet (Bottom View)

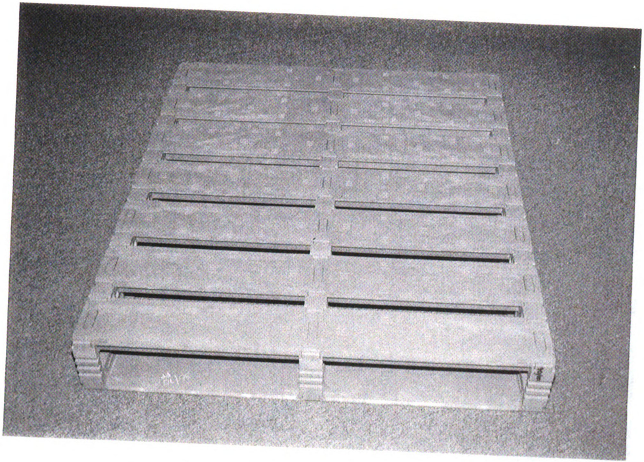

Figure 13. Injection Molded Plastic Pallet (Top View)

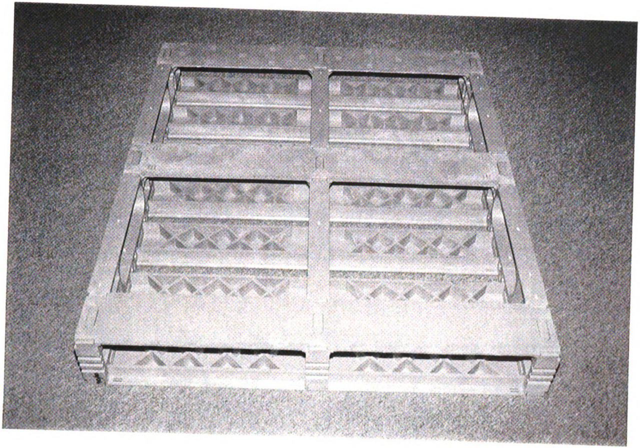

Figure 14. Injection Molded Plastic Pallet (Bottom View)

Figure 15. Stringer Type Wood Pallet (Top View)

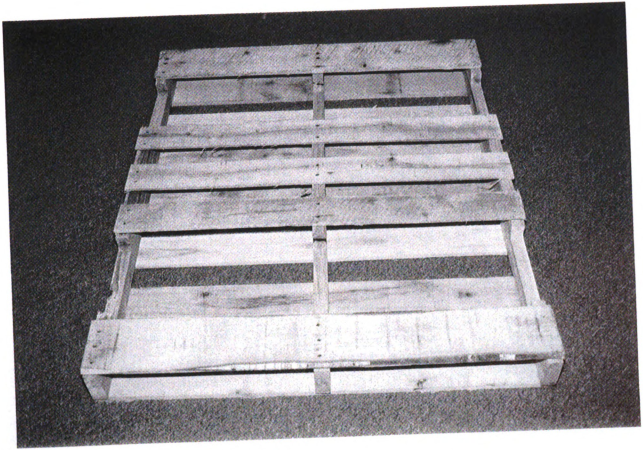

Figure 16. Stringer Type Wood Pallet (Bottom View)

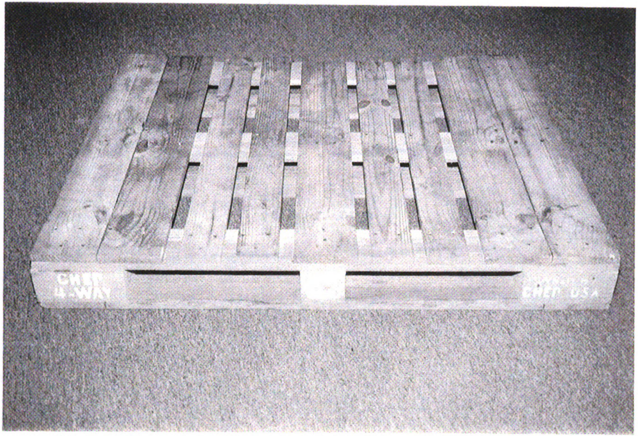

Figure 17. Block Style Wood Pallet (Top View)

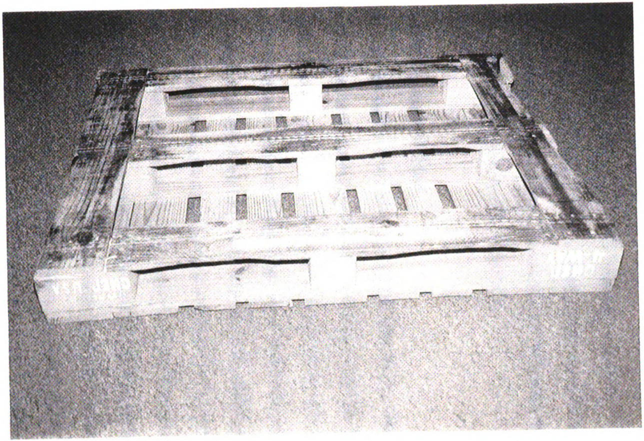

Figure 18. Block Style Wood Pallet (Bottom View)

2.2 TEST METHODS.

The pallets were subjected to various test methods to compare the relative performance of pallets fabricated from different materials to a specified performance criteria. The test methods include measurements of the relative resistance of pallets to deformation, damages, and structural failures which detrimentally affect the functionality of the unit load.

2.2.1 Static Compression Tests.

This test was performed to determine pallet stiffness and flexural strength under specified load and support conditions. It provides a basis for comparing the performance between pallets of different design and construction. A Gaynes compression tester with a maximum load capacity of 10,000 lbs. and a large bed to provide support for the pallet was used. The load was applied at 0.5 inch per minute. The test was performed in accordance with ASTM D-1185, Section 8.

The first pallet sample was placed on the compression tester bed, and a uniform distributed load was applied between the flat top and flat bottom platens as shown in Figure 19. The corresponding deflections were measured for every 2000 lbs. of load between the two decks of the pallet in the middle. The test was conducted for a maximum of 10,000 lbs. or failure of pallet which ever occurred first. All seven types of pallets were tested using the same procedure.

The second pallet sample was then loaded with concentrated line loads using line load spreaders. The pallet was placed on the compression tester with two plywood spreaders on the top deck and two on the bottom deck also shown in Figure 19. Each plywood spreader was 50 inches in length, 4 inches wide and 0.5 inches thick to support the pallet and transmit the load along the width of the pallet. The load was applied at a rate of 0.5 inch/minute. The corresponding deflections were measured for every 2000 lbs. of load between the two decks of the pallet in the middle. The test was conducted for a maximum of 10,000 lbs. or failure of pallet whichever occurred first. All seven pallets were tested using the same procedure.

The third pallet sample was then subjected to bending stiffness test. The bottom edges were placed on two steel pipes measuring 50 inches in length and 2 inches in diameter with enough stiffness as not to deflect more than 2 mm while the pallet was being tested. The pallet and the pipes were separated by the line load spreaders. Two additional pipes were placed on the top deck of the pallet with the line load spreaders separating them as shown in Figure 20. Then the compressive load was applied at a fixed rate of 0.5 inch per minute and the corresponding deflections were measured for every 2000 lbs. of load. The test was conducted for a maximum of 10,000 lbs. or failure of pallet whichever occurred first.

The fourth pallet sample was also subjected to a warehouse rack configuration test. The bottom edges were placed on steel pipes. The pallet and the pipes were separated by line load spreaders and an air bag was placed on the top deck of the pallet and the compression tester platen as shown in Figure 21.

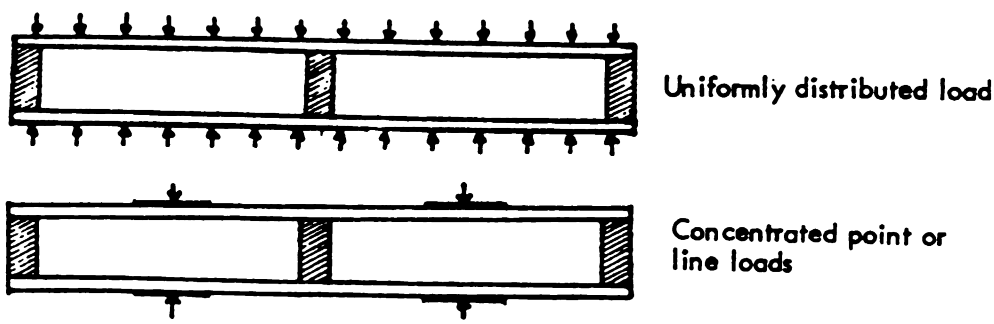

Figure 19. Pallet with Uniformly Distributed and Line Loads

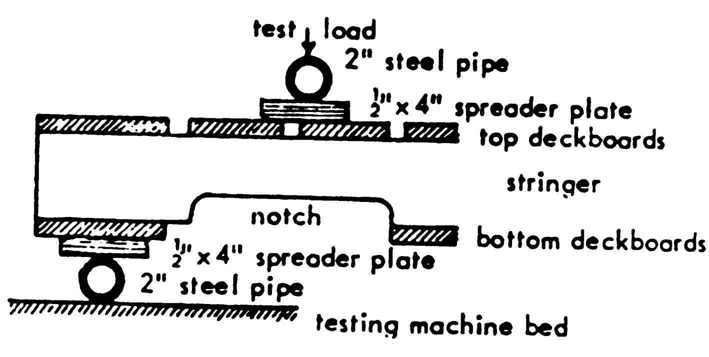

Figure 20. Loading and Supporting Details for Pallet to be Tested for Bending Stiffness

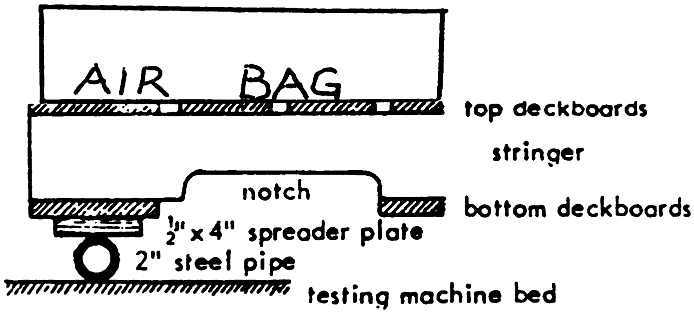

Figure 21. Loading and Supporting Details for Pallet to be Tested for Warehouse Racking

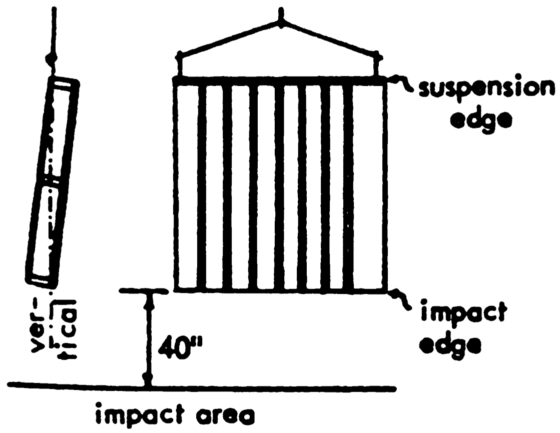

Figure 22. Edge Drop

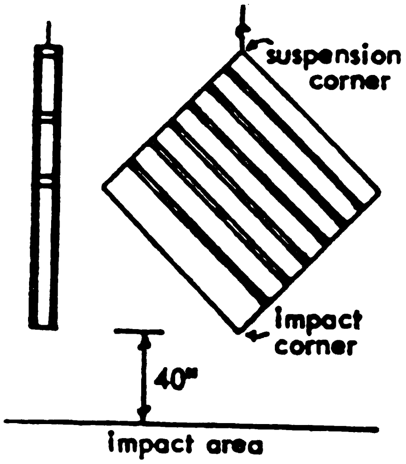

Figure 23. Corner Drop

Then the compressive load was applied at a fixed rate of 0.5 inch per minute and the corresponding deflections were measured for every 2000 lbs. of load. The test was conducted for a maximum of 10,000 lbs. or failure of pallet whichever occurred first.

2.2.2 Dynamic Tests.

Vibration Test.

The first dynamic test consisted of subjected a loaded pallet to a vibration test. This test was performed to see the effect of various dynamic forces that pallets are subjected to during transportation. The test pallet was loaded with 2000 lbs. The load consisted of corrugated boxes containing dead weights encapsulated in cushions. The load was then stretch wrapped on the pallet and placed on a Lansmont electro-hydraulic vibration table and restrained on all four sides of the pallet load to prevent lateral movement. A frequency scan was performed from 2 Hz. to 100 Hz. at a sweep rate of 1 octave per minute with a constant acceleration of 0.25 G's as recommended in ASTM D-999, Method C. The resonant frequency of the palletized load was determined. The pallet load was tested for a vibration dwell of 60 minutes at this resonance condition. All seven pallets were tested using the above procedure in sequence

Lateral Stability and Diagonal Rigidity of the Pallet.

The purpose of this test is to determine the lateral stability of a pallet and its resistance to impact forces in the pallet plane perpendicular to the pallet sides. The test also determines the diagonal rigidity is its resistance to impact and racking forces in the pallet plane. The test was performed in accordance with ASTM D-1185 standard. All drops were performed on a Lansmont Precision Drop Tester.

To determine the lateral stability and diagonal rigidity the pallet sample was dropped from a fixed height of 40 inches as shown in Figure 22 and 23. The drop sequence used is described below:

NUMBER OF DROPS	IMPACT SURFACE
Three	Pallet corner
One	Adjacent pallet corner
One	Pallet end edge
One	Pallet side edge

After all drops were accomplished the pallet was examined for any damage. The pallets were subjected to a second drop sequence after completion of the multiple handling sequence described in the next section.

Slue Resistance and Abrasion to Feet due to Fork Truck Handling.

The pallet sample was then subjected to a multiple handling sequence in an actual warehouse condition. The pallets were loaded with 2000 lbs. of dead weight and subjected to a repetitive handling sequence using a counter balanced fork lift truck. The following impacts were conducted on the pallet.

NUMBER OF IMPACTS	IMPACT TEST CONDITION
Four	Leading edge Fork-Heel Impact
Four	Fork Toe Impact (Pallet Feet)
Four	Leading edge Deckboard Separation Resistance
Four	Sluing (Rotate pallet 90 using forks)

The palletized load was handled with normal conditions between each impact sequence. The pallets were subjected to ten complete repetitions of the above sequence.

The last part of this test consisted of pushing and sliding the palletized load on the floor for a distance of 25 feet. This was repeated four times.
The pallets were then unloaded and subjected to a second series of six drops from 40 inches on the Precision Drop tester as described in the previous section.

2.3 FAILURE CRITERIA.

The pallets were then inspected for damage. A failure criteria was developed to evaluate the performance of the various pallets after completion of all tests. Two separate types of failure criteria were used to evaluate the Plastic and Wood pallets.

2.3.1 Failure Criteria used for Plastic Pallets.

Failure criterion	Description
a	Any corner leg broken such that the leg cannot rest on level surface

b	Any corner leg missing
c	Center leg broken or missing such that the leg cannot rest on level surface
d	Any cracks three inches or longer
e	Pallet deck deformation which includes cracks along pallet edges, corners or leg assembly

2.3.2 Failure Criteria used for Wood Pallets.

Failure criterion	Description
a	Any block or stringer that is damaged permanently due to a fracture
b	Any leading deckboards that are split
c	Any deckboards that are split or fractured
d	Any deckboards that are loose and have protruding nails

3.0 DATA AND RESULTS

The data collected and the comparison of the different pallets is discussed in this chapter. The results of the first static compression test are shown in Table 2. All seven types of pallets showed negligible deflection and no damage for loading up to 10,000 lbs. The results of the second compression test are shown in Table 3. All seven types of pallets showed negligible deflection and no damage for loading up to 10,000 lbs. The data for the third compression test is shown in Table 4. Pallets F and G were badly damaged (fractured) at compression loads of 2000 and 3000 lbs. respectively. Pallets B and E showed deformation exceeding 4 inches across the mid-span of the pallet (bottom-out) for loads of approximately 2000 lbs. and therefore failed this test at 2000 lbs. Pallet A showed similar deformations for a load of 4000 lbs. Pallet C showed this deformation at 5000 lbs., and Pallet D bottomed out at a load of 6000 lbs. The pallets can therefore be ranked as C, B, A, G, D/E/F in order of decreasing strength.

The data for the fourth compression test is shown in Table 5. Pallet F was damaged (fractured) at a compression load of 2000 lbs. Pallets A, B, C, and D showed deformation exceeding 4 inches across the mid-span of the pallet (bottom-out) for loads of approximately 2000 lbs. and therefore failed this test at 2000 lbs. Pallets E and G performed the best and bottomed out at a load of 5000 lbs. Based on this test the pallets can be ranked as E/G, A/B/C/D/F in order of decreasing strength.

The data for the first dynamic test using a drop sequence is presented in Table 6. Pallets B and D showed some visible damage after this test. Pallet B had a bent corner after the first corner drop. Although the corner was depressed inward there was no visible damage and the pallet could still be safely used. Pallet D showed a 2 inch crack after the first corner drop. This pallet could still be used to handle pallet loads. All the remainder pallet types showed no visible damage.

Two samples of each pallet type were subjected to the dynamic tests and the multiple use warehouse tests. The number of failures per criterion for each pallet and sample are summarized in Table 7. The results of these tests for each pallet type are briefly discussed in this section.

PALLET A.

Both samples of pallet had a broken corner leg, and two broken center legs, which in turn makes the pallet less stable during transportation and handling. The pallet sample 2 had an additional failure in form of a crack that ran from one of the corner legs to the top deck of the pallet. The total number of failures for sample 1 were three and for sample 2 were four.

PALLET B:

All of the legs in both the samples were intact after the tests. The pallet sample 1 had two cracks longer than three inches in the top deck area. Sample 2 did not show any cracks. There was no deformation of the deck but the corners of both the samples were bent. Total number of failures for sample 1 were three and for sample 2 were one.

PALLET C:

There were no legs damaged or missing from either one of the samples. The top deck was straight and no visible signs of deformation were found. Both samples had zero failures. This pallet showed the best performance.

PALLET D:

Both samples had all legs intact. One of the sample pallet had a center leg broken that made the pallet unstable. Both sample pallets had their corners torn with cracks. Total number of failures for sample 1 were two and for sample 2 were one.

PALLET E:

This double faced pallet had no feet, but there was no damage to the runners on the bottom. The top deck was also without any deformation or cracks. Sample 1 and sample 2 had zero failures. This pallet also showed the best performance.

PALLET F:

Sample 2 in case of this stringer type wood pallet had a fractured stringer.

The leading deckboards of both the samples were split apart. The deckboards of both the sample pallets were loose with protruding nails, but they were still intact to the stringers. Sample 1 had a deckboard loose. Total number of failures for sample 1 were three and for sample 2 were two.

PALLET G:

All blocks on both the sample of this block type pallet were damage free. Both the leading deckboard of sample 1 and one leading deckboard of sample 2 were split. In case of sample 1 one of the deckboards was split and in case of sample 2 five of the deckboards were either split or fractured. In sample 1 one of the deckboards being loose had a protruding nail. Sample 2 had two deckboards with protruding nails. Total number of failures for sample 1 were four and for sample 2 were eight.

To summarize the data, Table 7 also lists the average number of failures per criterion. This column shows that pallets C & E were the top performing pallets with zero failures. Pallet G was the worst performer with an average of six failures per pallet.

Based on a recent study by the USPS (USPS Pallet Life Cycle Test, 1994) an ideal pallet should have the following characteristics:

- Should be Low Weight (ergonomics, material cost)
- Should be Low Cost (material and process dependent)
- Last the Maximum Number of Trips

- Be Environmentally Good (recyclable)

This was found to be true in this study where the light weight plastic pallets showed more damage than the heavy duty made from the same process (thermoforming). In general the wood pallets and the injection molded plastic pallet weight are over 40 lbs. which make them less suitable for safe ergonomic manual handling. These three pallets are also not nestable and would require more storage space and higher per pallet shipping costs. The HDPE thermoformed pallets have the best recycling capability since the HDPE sheet can be ground back into pallets. Wood pallets currently have serious disposal issues. However they are cheaper to repair and are being currently used in pallet pooling operations. Table 8 provides a general comparison between major pallets type considered in this study. A comparison is provided for the corrugated pallets which were not tested for multiple warehouse cycles or warehouse racking requirements since they are principally used in one way shipments.

TABLE 3: Deformation of Pallets after Second Compression Test

Pallet Type	**Deformation (Inches) for Various Loads**				
	2000	4000	6000	8000	10000
A	negligible	negligible	negligible	negligible	no damage
B	negligible	negligible	negligible	negligible	no damage
C	negligible	negligible	negligible	negligible	no damage
D	negligible	negligible	negligible	negligible	no damage
E	negligible	negligible	negligible	negligible	no damage
F	negligible	negligible	negligible	negligible	no damage
G	negligible	negligible	negligible	negligible	no damage

* Negligible deflection was less than 0.125 inches.

TABLE 4: Deformation of Pallets after Third Compression Test

Pallet Type	**Deformation (inches) for Various Loads**					
	1000	2000	3000	4000	5000	6000
A	0.393	0.590	0.866	Bottomed	-	-
B	0.590	0.905	1.023	1.259	Bottomed	-
C	0.511	0.708	0.984	1.299	1.377	Bottomed
D	Bottomed	-	-	-	-	-
E	0.393	Bottomed	-	-	-	-
F	0.196	Fractured	-	-	-	-
G	0.100	0.157	Fractured	-	-	-

TABLE 5: Deformation of Pallets after Fourth Compression Test

Pallet	**Deformation (inches) for Various Loads**					
Type	1000	2000	3000	4000	5000	6000
A	Bottomed	-	-	-	-	-
B	0.590	Bottomed	-	-	-	-
C	0.590	Bottomed	-	-	-	-
D	Bottomed	-	-	-	-	-
E	0.511	0.866	0.866	0.984	Bottomed	-
F	0.196	Fractured	-	-	-	-
G	0.551	0.787	0.984	1.062	Bottomed	-

TABLE 6: Results of Drop Tests

	Pallet Corner	Adjacent Pallet Corner	Pallet End Edge	Pallet Side Edge
	3 Drops	1 Drop	1 Drop	1 Drop
A	no damage	no damage	no damage	no damage
B	Corner Bent	no damage	no damage	no damage
C	no damage	no damage	no damage	no damage
D	Corner Cracked	no damage	no damage	no damage
E	no damage	no damage	no damage	no damage
F	no damage	no damage	no damage	no damage
G	no damage	no damage	no damage	no damage

TABLE 7: Failures per Criterion for Pallets after Multiple Warehouse Tests

Pallet Type	Pallet Sample	Number of Failures per Criterion					Total	Average
		a	b	c	d	e		
A	1	1	0	2	0	0	3	3.5
	2	1	0	2	1	0	4	
B	1	0	0	0	2	1	3	2
	2	0	0	0	0	1	1	
C	1	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	
D	1	0	0	1	1	0	2	1.5
	2	0	0	0	1	0	1	
E	1	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	
F	1	0	2	0	1	-	3	2.5
	2	1	1	0	0	-	2	
G	1	0	2	1	1	-	4	6
	2	0	1	5	2	-	8	

TABLE 8: Relative Comparison of Various Pallets

PALLET TYPE	Weight			Cost			Compression (Uniform Distributed Load)			Compression (Rackability)			Multiple Handling Cycles		
	High	Med.	Low	High	Med.	Low	Good	Avg.	Poor	Good	Avg.	Poor	Good	Avg.	Poor
A			X	X			X					X			X
B			X		X		X					X		X	
C		X			X		X					X	X		
D			X			X	X					X		X	
E	X			X			X					X	X		
F	X					X	X					X			X
G	X					X	X			X					X
H			X			X	X					X			X

PALLET CODE

A - HDPE STRUCTURAL FOAM, 22 lbs.
B - HDPE TWIN SHEET THERMOFORMED (LIGHT GAUGE), 20 lbs.
C - HDPE TWIN SHEET THERMOFORMED (HEAVY GAUGE), 31 lbs.
D - HDPE SINGLE SHEET VACUUM FORMED, 18 lbs.
E - HDPE INJECTION MOLDED, 55 lbs.
F - WOOD STRINGER PALLET, 47 lbs.
G - WOOD BLOCK PALLET, 60 lbs.
H - KRAFT PAPER CORRUGATED PALLET (NOT TESTED), 10 lbs.

TABLE 8: Relative Comparison of Various Pallets (Continued)

PALLET TYPE	Environmental Factors Disposal/Recyclability			Nestability			Interlocking Load Stability			Repairability			Multiple Transportation Cycles		
	Good	Avg.	Poor	Good	Avg.	Poor	Good	Avg.	Poor	Good	Avg.	Poor	Good	Avg.	Poor
A		X		X				X				X	X		
B	X			X				X				X	X		
C	X			X				X				X	X		
D	X			X			X					X	X		
E	X					X			X	X			X		
F			X			X			X	X				X	
G			X			X			X	X				X	
H	X					X			X			X			X

PALLET CODE

A - HDPE STRUCTURAL FOAM, 22 lbs.
B - HDPE TWIN SHEET THERMOFORMED (LIGHT GAUGE), 20 lbs.
C - HDPE TWIN SHEET THERMOFORMED (HEAVY GAUGE), 31 lbs.
D - HDPE SINGLE SHEET VACUUM FORMED, 18 lbs.
E - HDPE INJECTION MOLDED, 55 lbs.
F - WOOD STRINGER PALLET, 47 lbs.
G - WOOD BLOCK PALLET, 60 lbs.
H - KRAFT PAPER CORRUGATED PALLET (NOT TESTED), 10 lbs.

4.0 CONCLUSIONS

Seven types of pallets fabricated from various materials were tested to compare their relative performance under a specified performance criteria. The study concluded the following:

1. Plastic pallets performed better than wood pallets.
2. Among the plastic pallets tested the Twin Sheet Thermoformed Pallet (Weightlifter, 31 lbs.) performed the best followed by the heavier Injection Molded (55 lbs.) pallet.
3. Among the wood pallets the block style pallet showed better performance than stringer style pallets.

The study showed that certain pallets will perform better than others based on various design features that permit them to be nestable, provide load stability, and last several multiple trips.

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