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Manual Rubber Sandal Press for Loisaba Kenya

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Abstract

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The goal of this project was to develop an inexpensive manual cutting machine to cut sandals out of recycled tires and industrial belt allowing poor Kenya villages to produce their own sandals that are durable enough to survive the rough terrain. In Kenya 56 percent of the population live in poverty, surviving on less than a dollar a day. Walking is the main mode of transportation and the majority of Kenyans can only afford second hand shoes that wear out easily on the unpaved roads. In developing this machine the goal was to make the machine affordable for a company in Kenya to make and sell to local villages who can in turn use this machine to make a profit selling affordable shoes. In the design of this machine special attention was paid to the materials and tools available to manufacture in these poor areas along with the cost of manufacturing.

The final design for this press utilized a double toggle linkage to increase a manually applied load. The linkage was modeled after a stone crusher linkage and a mechanical advantage analysis of 3.75 was calculated at the moment the cutting blade contacted the rubber. A simple hollow cube frame was used to support the linkage and a stress simulation analysis was complete which proved a wooden frame would not break under the loading. A prototype was made with basic tools and materials by hand and a sample of tire was successful cut.

Executive Summary

The Loisaba Community Conservation Foundation is a ranch in the middle of Laikipiak Plateau in Kenya which provides a refuge for native species of animals and allows the local Masaai and Samburu tribes the opportunity for employment and sustainable agriculture. This organization works to help these marginalized tribes by providing them access to education and employment opportunities but still many people in this region, like in many rural regions, lack access to affordable footwear which makes them more prone to injury and parasites. With walking the main mode of transportation for these people, foot injuries can force them to miss weeks of work or school or even strand them in the middle of the safari vulnerable to predators.

Many people living in rural Kenya make less than a less than a dollar a day and rely on mostly bartering, rather than money, to obtain goods. These people have limited means to purchase shoes because bartering is not as accepted in larger cities and shoes are not generally sold in rural areas. To make footwear more accessible and affordable for these rural regions, therefore, a means to produce their own shoes to barter or sell would be beneficial. For this reason Tony Hynes, a local entrepreneur, requested a manual press to cut sandals from industrial belt and tire, to provide a rural village with a means to create their own durable sandals.

This report presents a very viable sandal press design that not only provides an extremely energy-efficient method to cut sandals using a double toggle linkage, but a design portable enough to for a person to carry home on foot. This press was designed to be fabricated in a Kenyan factory from wood and stainless steel at a cost less than a hundred dollars. The linkage was selected based on a mechanical advantage analysis which determined an initial mechanical advantage of 3.75 on contact with the rubber, this advantage then exponentially increased as the linkage approached a double toggle position at the end of the cut. To ensure the link wouldn't break a stress analysis of a SolidWork's model was simulated for the linkage under an excessive load, from this pine proved a viable linkage material with a calculated a

minimum factor of safety of 1.82. A pine and stainless steel prototype was built by hand to ensure a simply design fabrication, and the prototype performance proved successful in that the press was able to cut through small sections of rayon-belted tire.

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[1] Introduction

The percentage of starving people in sub-Saharan Africa dropped three percent, from twenty percent to seventeen percent, over the twelve year span from 1990 to 2002, however the absolute number of starving people increased by 140 million [4]. The root cause of hunger is poverty. Sub-Saharan Africa is a developing region with the highest number of people living in extreme poverty, so it comes as no surprise that this region also represents the majority of third world countries found in the world today [3]. More than seventy percent of sub-Saharan Africans live in rural areas, engaged in mostly agriculture and farming [2]. The limited tools and resources available to farmers, along with natural disasters such as drought, prevent many farmers from increasing their production, which thereby keeps them from increasing their income. The industrialization of these regions hasn't been helping much either, as it has led to a widening gap between the rich and the poor as industry mainly provides products for the rich minority.

In the early development of new industries, most were located in existing industrial areas which centered around mines, railways, and ports, and focused on the development of manufactured machinery, equipment, and consumer items primarily for the narrow high-income market [7]. These industries produced only a few broadly consumed items for the black majority, whose low incomes drastically limited their purchasing power [7]. These industries depended heavily on imported machinery, equipment, and materials, and so provided relatively few local jobs. To survive, many farmers turned to semi-substance cultivation where they use their crops to feed themselves rather than sell in the market since industries tended to favor minority owned commercial farms [7]. Most of the farmers in sub-Saharan regions are stuck in the 'dark ages' of agriculture as these countries are also too small to afford large expenditures in agricultural development.

Forty-four percent of the farmers in these sub-Saharan regions make a little less than a dollar a day and the average rise per capitia growth rate for the past forty years has stayed close to zero, as seen in

figure 1 [4]. Millions of dollars of aid is poured in to Africa each year to reduce poverty, but there has been little to show for these large investments which have come in the form of donations. Other countries have seen some improvement in the dollar a day percentage, as the percentage of people living on less than a dollar a day in developing countries decreased from 27.9 percent to 19.4 percent [4]. Most of this improvement came from China where the percentage dropped from thirty-three percent to seventeen percent, halving the percent of extremely poor people [4]. This drop in poverty in China did not arise from the help of foreign aid but rather because the government of China reversed the agricultural policy of collectivization allowing small-acreage farmers to start producing for the market [4]. The main issue that needs to be addressed in sub-Saharan regions is improving the purchasing power of the poverty stricken farmers so they buy the food, clothing and education they need, and as seen from China's drastic achievement, this cannot be achieved just through foreign aid, there needs to be policy changes to help assist farmers.

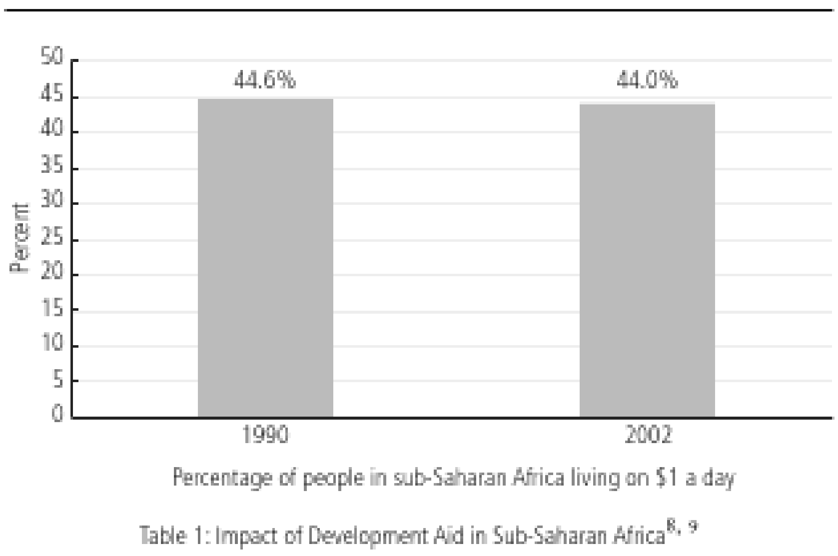


Figure 1: Graph of the percentage of people in sub-Saharan Africa living on a dollar a day in 1990 and 2002, from Out of Poverty.

The problem with donations is that while they provide instant relief and gratification they always fall short in the long term. Most forms of aid today just make people dependant on donations rather than improving the root of the problem, the lack of income. As seen in sub-Saharan Africa in the past forty-two years $568 billion dollars of aid has gone into Africa and yet the growth in income per capita of the even the median African nation has remained close to zero [1]. What is needed more than aid for these poor people is purchasing power. Companies need to make products affordable enough for the poor farmers so they can buy more advanced equipment and improve their agricultural yields.

Paul Polak and his organization International Development Enterprises have spent the last twenty five years designing for low income people, allowing them to lift themselves out of poverty. International Development Enterprises and a few other organizations have developed improved treadle pumps that are cheaper and pump deeper, motorized rope-and-washer pumps for irrigation, lower-cost wind and solar pumping systems, improved low-cost well-drilling tools and fifteen-dollar scythes for harvesting rice, corn and wheat, all of which have helped improve small farms. The problem as Polak sees it is that people focus too much on donations because they believe that people that make less than a dollar are too poor to invest their own money to move out of poverty. The donations often do more harm than good though, as they are used for big infrastructure investments often controlled by the government which creates competition for small business owners which they often can't compete with. On the other hand organizations like Polak's International Development Enterprises have successfully helped over seventeen million small farmers to get out of the less than a dollar a day incomes by designing for the "other ninety percent" designing simple cheap solutions to everyday problems like agricultural irrigation and cultivation, the huge effect Polak's efforts have made for these poor farmers can be seen in figure 2.

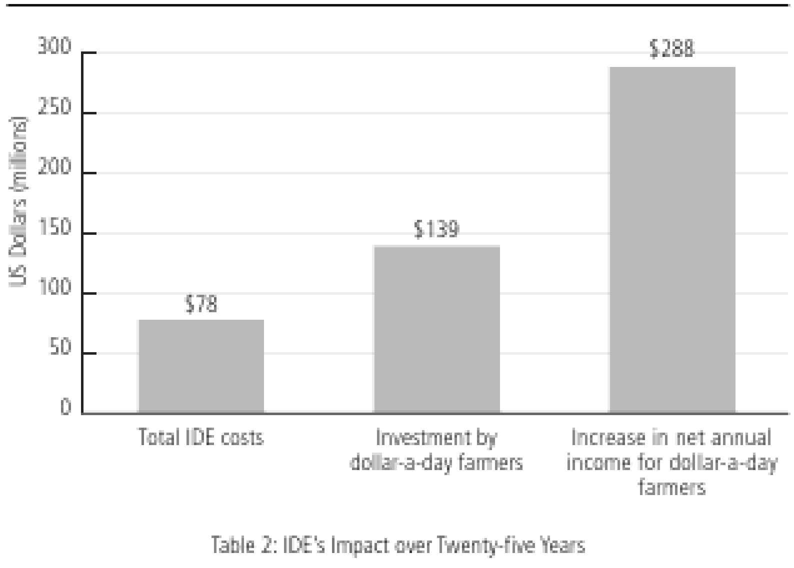


Figure 2: Graph illustrating the economic growth and benefits experienced by rural farmers due to agricultural improvements, form *Out of Poverty*.

In Kenya fifty-six percent of the population lives in poverty, surviving on a dollar a day. Walking is the main mode of transportation and the majority of Kenyans can only afford second hand shoes that wear out easily on the unpaved roads, or tire sandals. Local shoe producers find it difficult to compete with the low prices of the second-hand shoes and are reduced to selling cheap flip-flops. On the other hand tire-sandals have provided steady jobs and incomes for many young adults. Figure 3 shows how these tires sandals are typically made by hand. Some companies produce high quality, esthetically pleasing tire sandals with leather and beading but the main focus is on international sandal sales. High quality sandals that are affordable for the poor majority are hard to find and many often still can't afford the cheap tire sandals available.

Figure 3: Kenyan man cuts out the soles of tire sandals by hand, the most typical method to make these shoes, from www.theworldeffect.com

Tire sandals are cut by hand using typically a chisel or utility knife from recycled rayon or nylon belted tires rather than steel belted. Scrape tires constitute over twelve percent of all solid waste and because of their size, shape and physiochemical composition, they are relatively difficult to degrade or recycle [8]. 270 million car and truck tires are discarded each year and two billion have already accumulated in stockpiles which have been a major cause of global environmental pollution, figure 4 shows on tire stockpile from California. Stockpile fires emit tons of black smoke and chemicals into the air and the empty voids in the tires allow for air circulation which fuels the flames making the fires more difficult to extinguish so enabling them to last days or even months at a time. The empty voids also tend to collect water which provides an optimal breeding ground for mosquitoes. Not only have tires allowed for the transportation and introduction of different mosquito populations to other countries but also the mosquitoes present the danger of spreading diseases such as malaria and yellow fever which is a large problem in African countries. Due to the extreme poverty of the sub-Saharan region the magnitude of potentially fatal diseases running through the region is difficult to maintain. The Center of Disease

Control estimates that there are three to five hundred million cases of malaria each year, and more than one million people die.

Figure 4: Tire landfill in Westley, California in 1999 courtesy of http://www.edwardburtynsky.com

There are also many medical problems that arise from walking barefoot particularly from the Chigoe flea which is on the rise in Kenya. These fleas lives in dry-sandy areas and often burrow into the flesh of unsuspecting people. Exposed feet are particularly susceptible to these fleas as they are easily accessed as people walk around barefoot. The female fleas burrow into the flesh and will shed about one hundred eggs into the surrounding environment over a two week period. The females will remain burrowed in the skin feeding on the host and swell up to one centimeter in diameter creating extremely painful sores that not only make it difficult to walk but also causes severe foot deformities as seen in figure 5. When the female flea dies it also leaves the person susceptible to secondary bacterial infections. Many medical clinics do not treat the ailment leaving people to self-treat themselves using needles to extract the fleas and the unsanitary sharing of needles leads to the spread of other blood transmitted diseases such as HIV.

Figure 5: Jigger fleas are easily contracted and cause severe deformities that make it extremely painful courtesy of http://torietravels.blogspot.com/

The purpose of this project is to develop an inexpensive manual cutting machine to cut sandals out of recycled tires. This will allow poor Kenya villages to produce their own sandals that are durable enough to survive the rough terrain. In developing this machine the goal is to make the machine affordable for a company in Kenya to make and sell to local villages who can in turn use this machine to make a profit selling affordable shoes. The idea behind this project being that this will create more jobs and sources of income, and in turn improve the lifestyles of these poverty stricken people. In the design of this machine special attention will be paid to the materials and tools available to manufacture in these poor areas along with the cost of manufacturing so as to make a machine that will return the consumers investment within a year.

This report will first go through the functional decomposition of the design behavior and explore different possible approaches for each of the functions. A literature survey of relevant background material on the different approaches will also be presented to support the approach as each approach is explored. Specific design requirements will be presented along with the reasoning behind the requirements to determine the appropriate design criteria. From the design criteria and requirements each

approach will be evaluated to determine the most feasible design. Finally the final design will be presented and functions explained. Specific design calculations and performance estimates of the final design will be presented. A production schedule and cost analysis will also be put forward and a user's manual and project conclusions made.

[2] Background

The objective of this design is to build a machine that encompasses all the components to manufacture a rubber sandal from recycled rayon-belted tire or industrial belt. Currently the sandals and shoes available to the majority of Kenyans are primarily tire sandals, cheap flip flops or donated shoes which often times aren't even affordable enough to buy. The shoes these poor Kenyans do buy are usually easily worn out or poor quality for the rough landscape. Shoe soles are largely made of rubber or leather material. Due to the rough terrain of Africa and the higher cost of leather soled shoes however, the focus of this design project is on constructing shoes with the more durable and cheaper, rubber soles. Generally shoes soles are made in three layers known as the midsole, the insole and the outsole. These layers are all typically made of different materials from thermoplastics to rubber to maximize the comfort and performance of the shoes. In the creation of the outsole shoe manufactures utilize molds to form the rubber. A chunk of rubber of a company's special rubber compound is placed in the mold, heated at 350 degrees Fahrenheit and pressed into the mold, this process creates a vulcanized rubber that hardens to form the shoe soles. This process requires a variety of manufacturing steps and automated machines to guarantee quality hence, the shoes are more expensive.

Many third world countries where many people do not have the access to shoes or the money to buy these shoes create their own footwear from recycled material. Tire sandals are widely used and made in many poorer nations from countries in South America, Africa to Asia. The tire sandals they produce are cut out by hand with a metal blade or chisel from nylon-belted motorcycle tires. These provide affordable footwear but at the expense of quality, when compared to a shoe made in a factory. In the creation of a sandal press the goal is to improve the quality and accessibility of these cheaper shoes for poorer people. While there are currently no manual machines to cut shoes from recycled rubber to compare to or improve, there are many machines that have been developed to aid in the recycling of tires which have utilized various cutting techniques to cut through the varying tire compositions. The two

main functions in the making of this sandal are material preparation and sandal cutting. Both of these functions require a mechanism to generate a load and tool to cut the rubber material.

Depending on the tire composition the tire preparation can vary. For steel belted tires the removal and use of the side wall is necessary because the steel belting is difficult to cut manually, use of the side wall would be recommended for small children shoes sizes. A nylon or rayon belted tire on the other hand can be cut along the treads allowing for a larger variety of size sandals to be produced. Industrial belting is an ideal material to utilize because it is made in sheets of vulcanized rubber reinforced with a fabric-like material similar to a nylon belted tire but easier to cut. Some disadvantages to using industrial belt are that they are not commonly found so would have to be purchased new, and a sandal made from this material is made slightly differently than a tire sandal requiring two layers.

The construction of the industrial belt sandal requires two layers of industrial belt because of the material properties of the belt, it is difficult to form the strap supports from a belt thickness that is an ideal sole thickness so a thinner belt layer is required for the straps. These layers have to be glued together and clamped for a little less than a day to allow for the glue to dry. An advantage to the industrial belt however is that it is easier to prepare, the tire preparation requires the tire to be properly cleaned and precut to make it easier to cut. The sandal cutting requires a method to cut the sandal shape from the prepared material strip and a method to increase a manual inputted load in order to produce forces large enough to cut through the material more efficiently than cutting the sandal out by hand. With the industrial belt tires in addition a gluing and clamping step is necessary to finish the sandal. In the following sections different design functions will be explained and possible solutions explored from existing literature.

[2.1] Tire Preparation

One of the difficulties with using recycled tires is the varying size and composition of each tire and the hollow wheel shape of the tire. When the tire is prepped the side walls and steel bead are usually

cut away and the tire cut along its radius to enable the surface to be flattened out into a strip. All of the handmade tire sandals are made from a fabric-belted tire such as nylon-belted rather than steel-belted tire because of the difficulty in cutting the steel-belts by hand and the significant ware on the cutting blade.

Due to the variety in both the size and shape of recycled tires, if the cutting out of the tire walls and the transverse cut across the perimeter tread were to be mechanized, the versatility of a more maneuverable multi-cut method would be more favorable than attempting a single-cut method. Costs, materials, and electricity are limiting factors in the design of this machine so complicated cutting methods that require large quantities of electricity, or expensive or unavailable materials would not be ideal. This being said, this literature review will be comprised mainly of patents of the different tire cutting methods and machines from the past hundred years.

[2.1.1] Prep Cutting Methods

There are great deals of machine designs today to address the need to recycle or at least minimize the effect of tire waste. In the search for tire cutting technology the majority of what is to be found are machines to cut tires into more manageable shapes and sizes to eliminate the empty void that leads to the majority of tire waste issues. Though many of these designs would be too complicated to apply to the sandal cutting function they do present ideas for potential mechanisms to create very workable sheets of tire material from a tire. By taking the extra step to prepare sheets of tire to be cut into sandals it increases the simple design possibilities for the actual sandal cutting function. In the majority of tire cutting techniques researched a few key cutting approaches appeared in multiple designs: roller cutter, scissor, and slicing techniques. The utilization of these techniques will be reviewed further to determine the strengths and weaknesses of these potential design solutions.

[2.1.1.1] Roller Blade Techniques

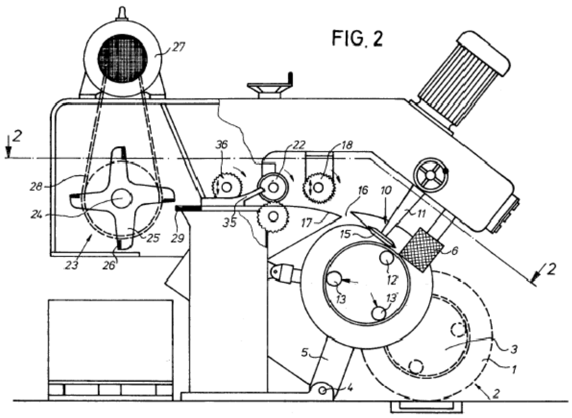


Figure 6: Drawing from Peter Schmidt patented method to granulate old tire. This illustrates the use of roller blades to cut tire. [17]

Peter Schmidt in 1982 patented a method for the manufacture of rubber granulate from old tires, in which he removes the steel bead, and cuts the sidewall and tire perimeter into multiple strips using circular knives and rollers [17]. To cut the steel bead from the tire Schmidt presses the opposite sidewalls together between two rollers and rotates the tire on its axis as seen in figure 6. A circular knife is then used to press the compressed tire walls against a transport roller which forces the knife to cut through the two layers of tire as the tire spins. The cut is started through the perimeter of the tire then adjusted so the blade cut as close to the steel bead as possible so that bead can be cut away and the tire flattened out to be cut into smaller strips. The flattened tire is cut into smaller strips by compressing the tire strip between a roller and more circular knives.

[2.1.1.2] Scissor Techniques

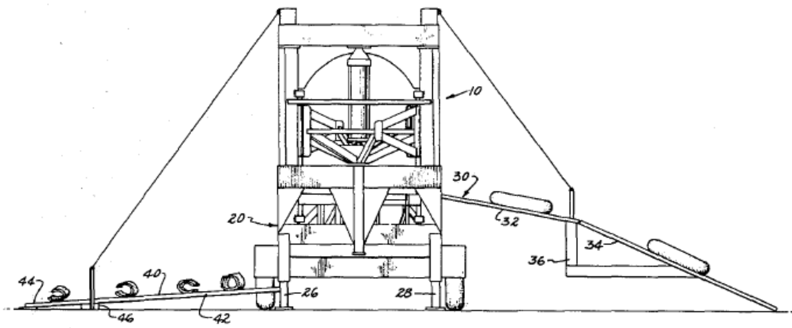


Figure 7: Warren Farrell's illustration of patented tire cutter that uses hydraulic press to cut through tire laying on it's side into multiple pieces [13]

Another tire cutting machine patented in the same year as Schmidt’s uses a scissor-like motion with shear-cutting blades as opposed to the roller motion and circular knives Schmidt’s design has [13]. Warren Farrell Sr.’s basic design cuts a tire into equal radial segments using multiple blades that cut the tire into sections with both sidewall and perimeter tread rather than separating the different tire sections as seen in figure 7. He does this using a hydraulic press to press opposing vertical blades in a shearing-cut motion through a tire lying on its side. The upper blades of Farrell’s design are all at an acute angle to not only the horizontal but also to the other blades, this staggers the cut times for each section slightly.

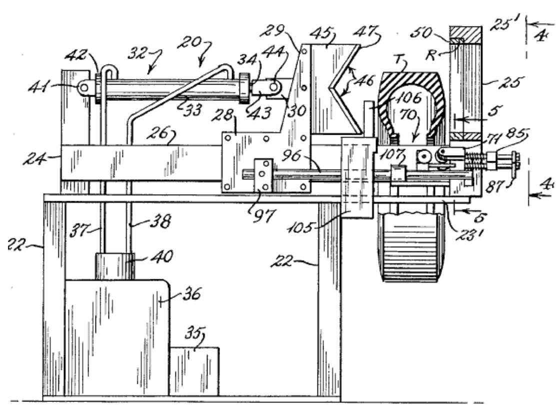


Figure 8: Schutt's patented design that utilizes a hydraulic press to cut through a tire with a varied blade [19].

Donald Schutt in his tire cutting design cuts a small section of the tire away at a time from the steel bead [19]. Supporting a tire by the steel bead the design mounts a tire on a mechanism that can be used to rotate the tire about a horizontal axis seen in figure 8. Two parallel blades set distances apart are positioned perpendicular to the side of the tire to cut out a small section of tire from the steel bead when the blades are actuated. A hydraulic ram is used to actuate the blades and force the parallel blades through the side of the tire which is supported on the other side be a die which causes the sheering of the tire as the blades cross each other and the section between the blades to be released from the tire. The tire is than easily rotated and cut again in the same fashion until all the remains in the steel bead and cut sections of tire.

[2.1.1.3] Single Blade Slice Techniques

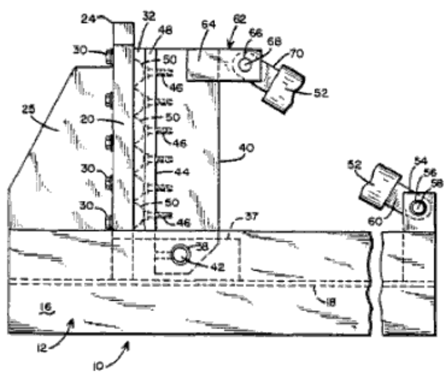


Figure 9: Raymond Schmidt's patented design which used a hydraulic ram to pull a pinned blade (40) down on a tire [17].

Raymond Schmidt designs a relatively simple machine that utilizes a single large blade actuated by a hydraulic ram to slice tires transversely into multiple smaller sections, seen in figure 9 [17]. The design is similar to a paper cutter with the blade on a pivot at one end and connected to the hydraulic ram at the other. The blade rests upright so a tire can be placed on the anvil in from of it. The hydraulic ram pulls down on the other end of the blade forcing it down onto the tire cutting it. The avail has a slit to prevent the blade from hitting the anvil when it completes its motion.

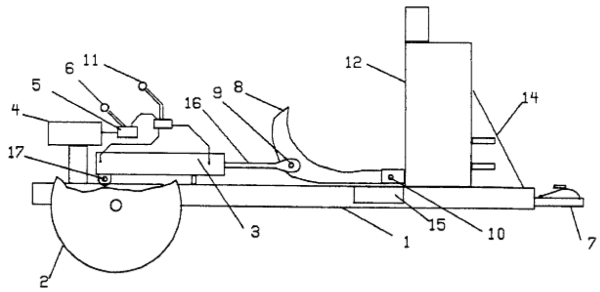


Figure 10: Dudley patented tire cutter, utilizes a hydraulic press to move a pinned blade and cut through large tires [12].

A couple years later in 1992 Joseph Dudley modified the design so as to make it more versatile by allowing it to cut larger tires [12]. As opposed to Raymond Schmidt, Dudley uses a hydraulic ram connected at the center of a pivoting blade to push the blade up and towards a vertical anvil, as seen in figure 10. To prevent the tire from riding up and over the free end of the blade during this motion Dudley curves the blade edge to contain the tire section.

[2.1.2] Alternative approaches

Another possible method that could potentially be used is to create strips of tire material is to cut the tire layers away circumferentially. If the methods for cutting steel belted tires explored above are not possible within the design limitation of this project then another solution is to attempt to separate the usable layers from the steel-belted layers which are unable to be cut. One possible approach is to use a sawing motion and serrated blade to cut tangentially into the steel-belted layer as the tire is rotated which could be done by hand seeing as how they already cut through these layers to make handmade tire sandals. Djavad Khadem patented the design of manufactured steel belted planks from scrap steel-threaded tire seen in figure 11. Similar to what is suggested above as an alternative to cutting through the steel threads Khadem wants to utilize scrap tire to make two-ply plank material by bonding two strips of scrap steel-threaded tires to make steel reinforced rubber plank to be profiled into a final product. The alternated design material industrial belts would be dealt with in a similar fashion.

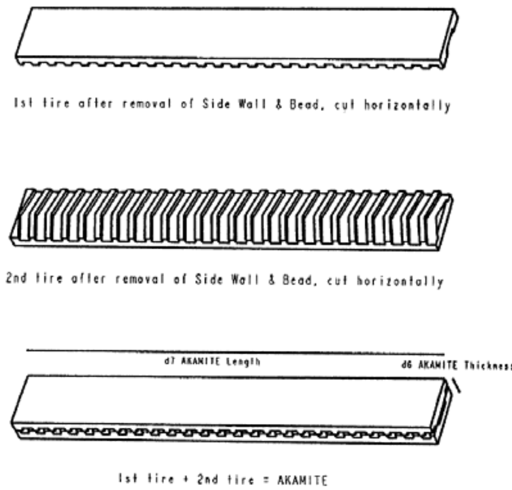


Figure 11: Alternative materials patent to create tire planks from multiple layers of tire [15]. If tire rubber could be removed from steel belts could glue together to create sole material.

[2.2] Sandal Cutting

With the preparation of the tire complete all that is left is a method to cut the different sandal shapes and sizes from the prepared material. To improve the quality and decrease the time it takes to cut out the sandal a press design was determined optimal. By utilized a press and dies to cut shapes from tire.

[2.2.1] Press Methods

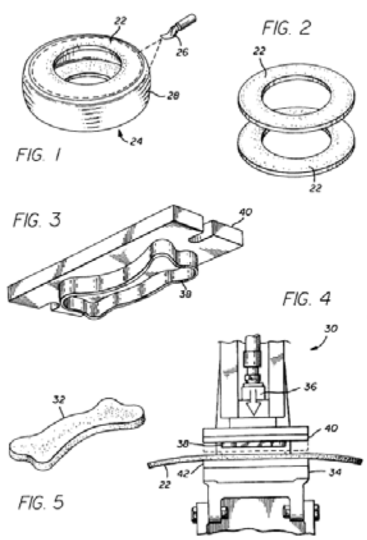


Figure 12: James Welch's design to cut dog toys from the side wall of tires using a die and an arbor press [21].

There is one patented design the specifically pertains to cutting tire into different shapes using dies. James Welch using a simple die and press design to cut chew toys for dogs from tire sidewalls as seen in figure 12 [21]. Using an arbor press Welch pressed dies onto tire sidewalls to cut out different shapes for the manufacturing of recycled chew toys. He did not use the tire treads because of the safety issues with pets playing with chew toys containing metal pieces, so it is unknown if the arbor press was also able to press shapes from the steel-threaded tread.

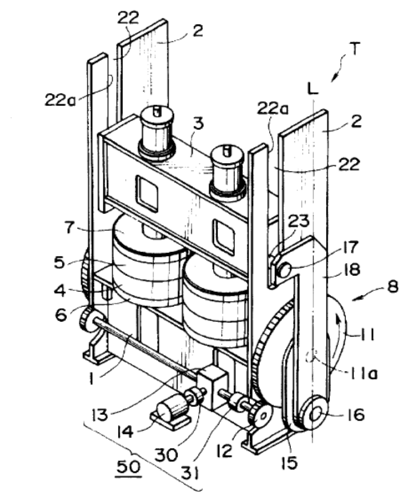


Figure 13: Fujieda patented manual tire press actuated by a crank [14].

Yasuhiko Fujieda design was actually one of the few manual designs found see in   figure 13. His design used a crank to press the tire between two molds by using a crank [14]. The design is uses a simple two bar linkage on either side of a slider that holds the top molds to open and close the mold. This design uses the toggle position of links to increase the mechanical advantage, actuated by a gear cranking system.

Another potential press is a hydraulic press which is capable of exerting much larger forces than an arbor press which may be needed. Many of the designs already mentioned in the cutting methods of the tire preparation use hydraulic rams to provide the force needed to allow blades to cut through the

steel-belted material. Pneumatic also presents an alternative method to actuate the cut with enough force the problem however is the high costs associated with these mechanisms.

[2.2.2] Cut and Extract

The use of dies is the most preferable method for this design because of the simplicity and ease of use. They also provide the fastest, cheapest method to cut rubber, fabric and leather material. The problem is with the steel belting, if a pressing approach will sever the steel threads of if a blade sawing motion is better for tire cutting. Researching current tire-cutting methods and machines suggests that a smooth blade is better for cutting the tire. A smooth non-serrated blade is also easier to maintain by hand sharpening. The die block material selection can also help maintain the blade more.

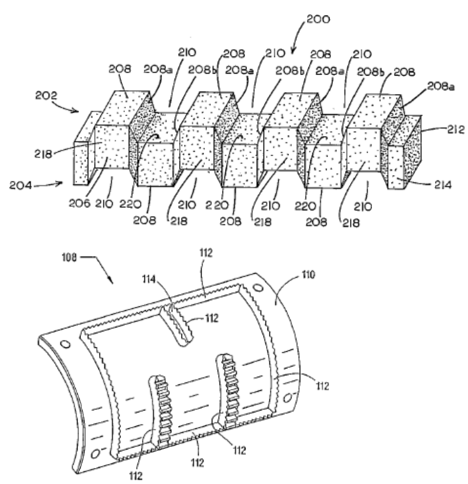


Figure 14: Smithwick's rubber ejection method, utilizes rubber to release the die cutout from the die [20].

After the sandal is cut the sandal must also have some method to be extracted for the die. Smithwick uses a rubber ejector that deforms during the die cutting and then as it returns back to shape, it forces the cutout out of the die seen in figure 14 [20]. Springs could also be used in a similar way. It could also be possible to have a little latch in the die that could, when released, push the cutout manually.

[3] Functional Decomposition

The goal in this design is to make a sandal press for a small rural village, where the majority if not all the population makes less than a dollar a day. With this in mind there are a few specific design criteria that are necessary for the success of this machine. This machine is not only meant to increase the quality, affordability and accessibility of sandals for rural Kenyan farmers who make less than a dollar a day, but is also supposed to be a means to start a business and generate more income for these people. The overall design is therefore judged based on following design criteria which not only assess the affordability of the design but also the practicality of the design for rural Kenya.

Looking at the design financially it not only needs to be affordable but also generate income and have a quick return on investment. Since this design is for the world's poorest people it has to be reasonably affordable for people who make less than a dollar a day, which means ideally less than a couple hundred dollars. This comes into play in not only the material costs but also the machining costs. The target customers are also very risk adverse so a quick return on investment of at most six months is also required so people will actually purchase this press and generate income using it. The difficulty is in competing with hand-made tire sandals which costs nothing really to make except time. The appeal of this press is efficiency and quality.

This design must also be manual because these rural areas don't have access to electricity so the machine must be extremely efficient at converting human power to mechanical power. This comes into play with the mechanism design, increasing the inputted force with mechanical advantage and the blade design. The design materials are also very critical in the design process. To support local businesses and create jobs in the community, the design must accommodate for the fabrication of the press to take place in Kenya from locally available materials. A simple size and weight constraint calculation can be calculated from the fact that the customers will have to carry this machine back to their village.

From the design criteria explained above general the design requirements categories: cost, safety, portability, durability, performance and manufacturability were selected to summarize the system requirements and these were weighted based on importance. Each potential design solution was then evaluated on a scale from one to ten for each of the design criteria, in terms of how well the solution met the specific design criteria outlined above. With the weighting factor, the potential solutions were ranked to reveal the most favorable design approach. For the first function, the input enhancing mechanism, design solutions analysis can be seen in table 1.

Table 1: Function 1: force enhancing mechanism analysis

	Cost	Safety	Portability	Durability	Performance	Manufacturability	RANK
Weighing Factor	0.22	0.12	0.18	0.15	0.18	0.15	1.0
Hydraulic Press	1	8	1	9	10	2	4.81
Gears	8	6	9	8	9	4	7.52
Cams	6	6	8	7	8	5	6.72
Linkages	9	7	8	7	8	9	8.1
Springs	6	5	9	6	4	4	5.76

Based on the design criteria linkages appeared to be the best method to mechanize the design mainly due to the low cost and ease of manufacturing. The hydraulic press provided the best performance and durability but suffered due to the high costs, low portability and difficulty in manufacturing. If the press was used it would be bought from a press manufacturer rather than built and would have to be driven to the village by a truck. Gears are a good alternative to linkages with better durability and performance but like the hydraulic press the fabrication of gears requires precision machining which makes it complicated to manufacture in Kenya. Springs and cams mainly fall in the middle because they generally didn't presented themselves as strong options for any of the categories when compared to the other options.

Table 2: Function 2: Cutting blade Analysis

	Cost	Safety	Portability	Durability	Performance	Manufacturability	RANK
Weighing Factor	0.22	0.12	0.18	0.15	0.18	0.15	1.0
Saw	9	5	8	7	6	8	7.5
Scissor	8	7	9	8	7	6	7.58
Die	8	7	7	8	9	9	7.66
Roller Blade	8	6	7	8	6	7	7.07

The blade design is of equal importance if not more important than the mechanism design because it greatly affects the force required to cut the rubber. All of the blades were pretty close in ranking, biggest benefit however for the die and the scissor is that the entire sandal sole could potentially be cut in one stroke. The saw and roller blade would require a guide to cut the shape from the rubber which would be similar to their current method of cutting the tire by hand. The die is the best method simply because it is the simplest single cut method which makes it the easiest to manufacture and it is the easiest to integrate into a linkage mechanism design.

[4] Preliminary Design

From the selected functional analysis methods chosen, a few different options were explored to decide on the finalized design. With linkages, different options that utilized toggle points to maximize the mechanical advantage were explored because the mechanical advantage exponentially increases to infinity as the link reaches the toggle point. This increase in mechanical advantage also makes a varying die blade very beneficial in the design so a few different blade shapes were explored. From tire cutting tests the initial piercing of the rubber was the most difficult part of cutting the tire, and a thin, pointed blade makes it infinitely easier to cut.

Few different linkage designs were researched for the mechanism design. Three in particular were chosen which utilize the toggle position to maximize the output force. The first was a linkage for a punch press, which is a simple four bar linkage with a single toggle point. The second linkage had two toggle points which maximized the force in the stone crusher linkage. The third linkage was a similar design to the stone crusher but twice the links and the force inputted at a slider rather than with a lever, this linkage was from a mold press. These linkages can be seen in figure 15.

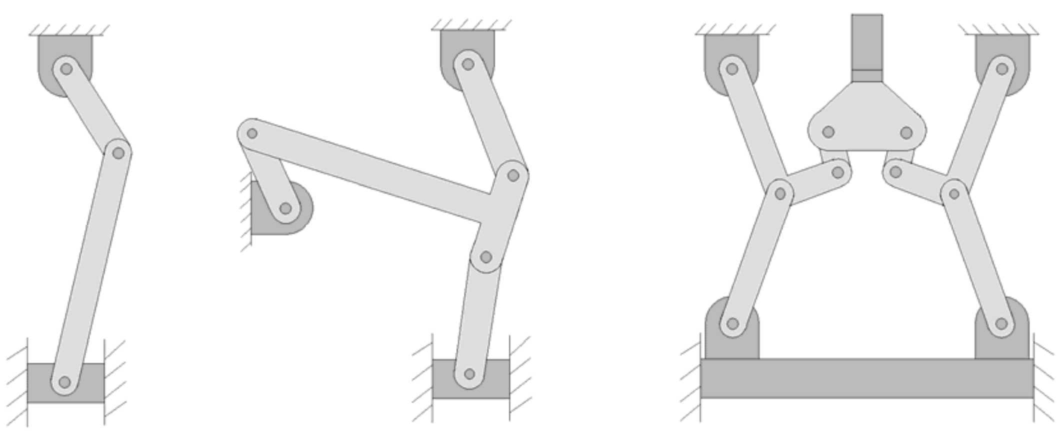


Figure 15: Potential linkage designs: punch press, stone crusher and mold press

[4.1] Mechanical Advantage Analysis

For each of these 1inkages the mechanical advantage at the point of first contact with the rubber was calculated. Holding the height of the linkage and the length of the drive link constant for each of the linkages the punch press actually had the greatest mechanical advantage with a mechanical advantage of 1.1 compared to the stone crusher which was slightly less than one at 0.67, as seen in figure 16. However, extending the drive link by five times increased the mechanical advantage by five times so a mechanical advantage of 3.75 could be realized. Even though the punch press had a better mechanical advantage the second linkage was chosen as the linkage to reduce the stresses on the linkages, so as not to break. The third linkage presented a good option to stabilize the sliding plate but the linkage added a lot of weight to the design and the fluidity of the motion was very sensitive to the length of the links.

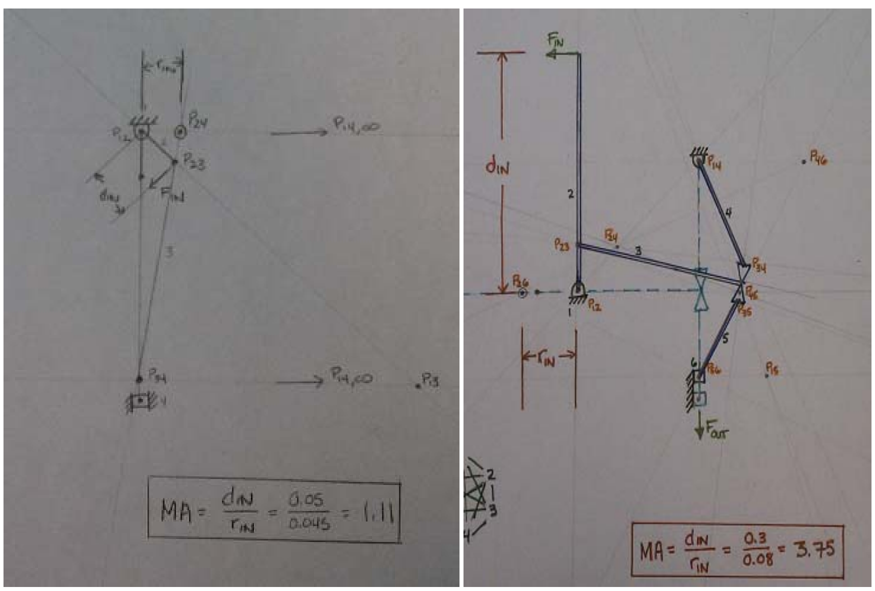


Figure 16: Mechanical Advantage analysis for toggle linkage options

With the mechanism chosen the blade design was next explored. By conducting cutting tests with various blades it was determined that a thin, sharp point in the blade was necessary to initiate the cut. Next the number of initial contact points had to be determined to find an ideal equilibrium between the steepness of the slope of the blade and the number of contact points. As more peaks are added to the

blade the more the blade slope could be varied, however, this also meant the more the force was divided resulting in less force at each peak the more peaks that were added. Different blade designs can be seen in figure 17.

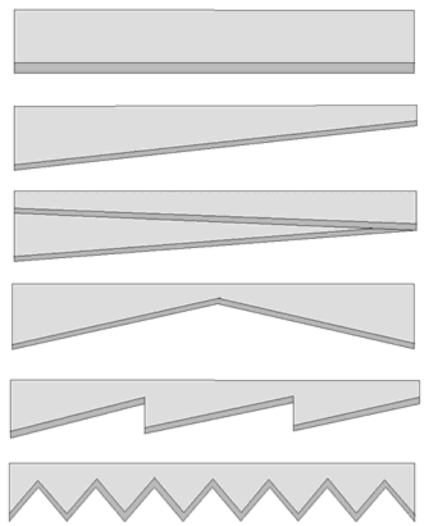


Figure 17: Side view of die to illustrate different potential blade designs, and the effect of the number of peaks on the blade slope.

For the preliminary design a simple rectangular box frame was utilized to support the linkage. This minimized the frame material while still providing a strong support for the linkage. The chosen linkage was attached on either side with levers in facing opposite directions to stabilize the press when the force is applied. A slider plate was attached to the free end of the linkage and is used to provide extra support for the die that is attached to a plate that can be slid into press. The die is formed in the shape of one sandal and can be switched out easily for different sizes. In the bottom of the frame rests the mirror image of the die shape cut into the base plate which allows the blade to pass through it while still supporting the rubber. This cut out support is necessary for a varied blade so that the die can cut through all the material. To remove the rubber form the blade two holes were cut out of the sliding plate to allow for the shoe to be pushed out of the die. Multiple views of the finalized design can be seen in figure 18 below.

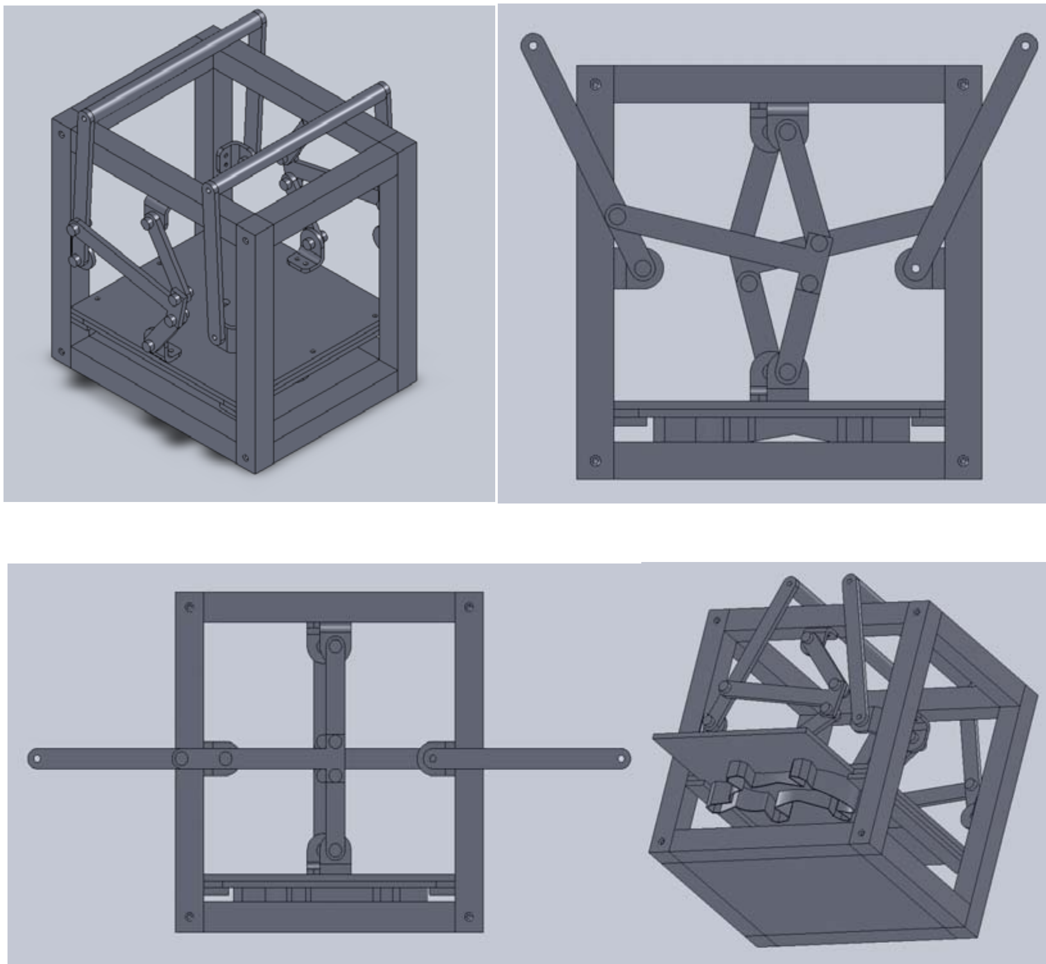


Figure 18: Finalized deign views from the top left: the point where contact with the rubber is initiated, top right: intermediate view of the mechanism, bottom left: double toggle point initiated, cut complete, bottom right: illustrates die plate removal for exchange

[4.2] SolidWorks Stress Analysis

To analyze the use of different materials in the design a stress analysis was completed using SolidWorks simulation. Making the entire design out of metal was not an option because of the excessive weight and material costs so a wooden frame made of pine was simulated with a couple different linkage material options. Seen in figure 19 is a factor of safety analysis with aluminum linkages, which had a minimum factor of safety of 2.41. This was compared to a stainless steel linkage and a complete pine linkage factor of safety analysis which can be seen in figures 20 and 21, respectively. Minimum factors of safety of 3.32 and 1.82 were calculated for the stainless steel and pine linkages, respectively.

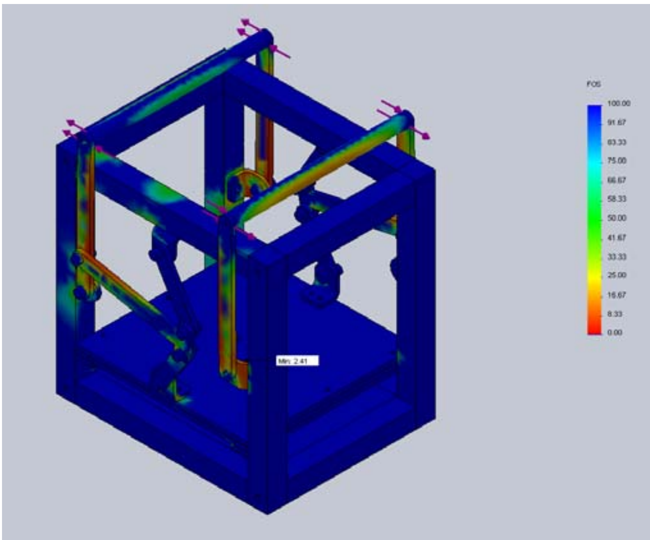


Figure 19: SolidWorks stress analysis simulation with aluminum linkages with 500 N force applied to the handles.

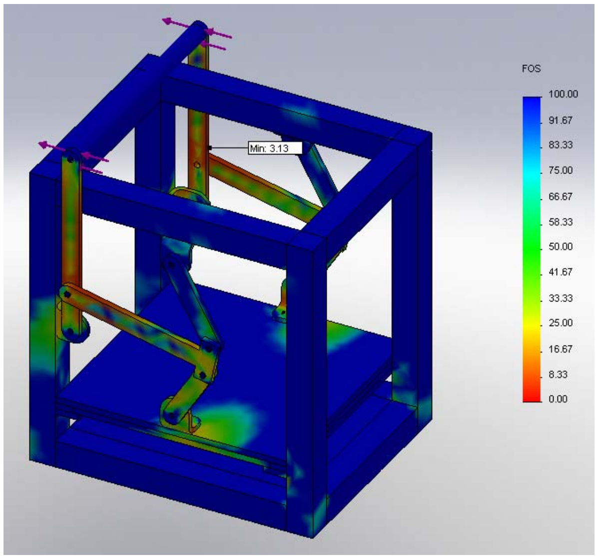


Figure 20: SolidWorks stress analysis simulation with stainless steel linkages with 500 N force applied to the handle.

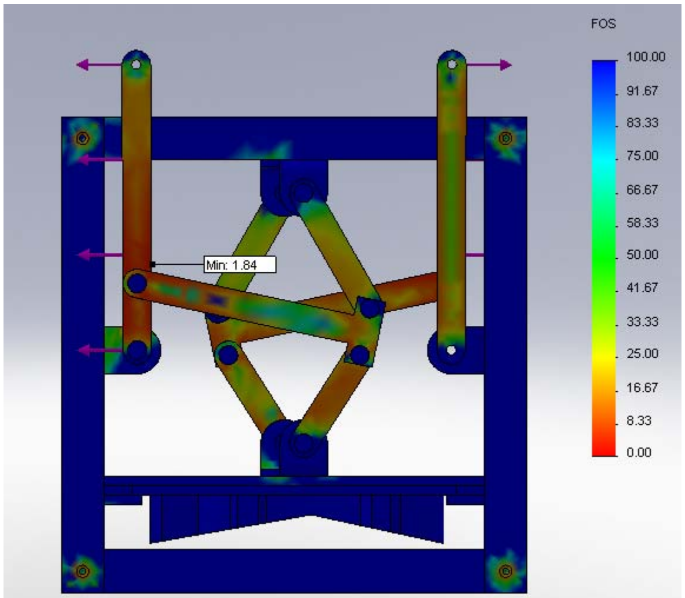


Figure 21: SolidWorks stress analysis simulation with pine linkages with a 500 N force applied to the handles.

From this analysis a prototype mainly made of wood seemed viable to make a test to compare to the simulation. Of the three options, the pine significantly reduced the design costs and weight, which made it the most appealing but at the expense of durability. Comparing the mechanical properties of pine to trees native to Kenya, pine is most similar to African mahogany, so it the wood model seems durable enough this could be made of African mahogany in Kenya.

[4.3] Fabrication

In the fabrication of this design it was important to use tools that were most similar to the technology available to a factory in Kenya since the desire of the project was a machine that could be fabricated in Kenya. To best replicate these tools only basic electric tools including: a table saw, a jig saw, a bench top drill press, an angle grinder and an electric screwdriver were used to build the prototype seen in figure 22. Some design modifications were utilized in the prototype based on the materials available in the local hardware store to minimize the difficulties in machining and enhance the design. The fabrication of the press was broken up along the two functional groups: the mechanism and the die.

Figure 22: First sandal press prototype fabricated using pine and stainless steel and basic machinery.

[4.3.1] Mechanism Fabrication

The first potion of the design to be cut and assembled was the frame to support the linkage. The frame was constructed from 2x3 sand pine multi-purpose studs. A combination of screws, steel mending plates and corner brakes were used to connect the frame. The mending plates were hammered across the connection of the two boards on the wider faces of the studs seen in figure 23 and corner brackets were attached to the top board to provide extra strength and to prevent the board from turning when the load was applied. Four 2” screws, one for each corner, were used to connect the front assembly to the sides. The 3/8” holes for the pins to support the linkage were then measures and drilled into the frame with a drill press.

Figure 23: Sandal Press frame assembled.

The links were then measured and cut from 23/32” sand pine plywood. The holes for the pins were measured and drilled using a 3/8” drill bit. The drive links required a counter bore in for the hole where the drive link connected to the frame to prevent the pin from hitting the other link when approaching the toggle position. The linkage was laid out on the frame to double check the lengths and holes then the linkage was assembled completely using 3/8” bolts as the pin. 3/8” x 3-1/2” bolts were used to connect the links to the frame and 3/8” x 2-1/2” bolts were used for the link to link connections. Washers were used between linkages as spacers to correct for any slight warps in the board which inhibited the link motion, and all the bolts were double nutted to secure the bolt. The motion was tested and the double toggle point was checked to make sure the links aligned at the same instant.

[4.3.2] Die Fabrication

The first step in the die fabrication was to construct the sliding plate that supports the die and presses it into the rubber. The sliding plate was first cut from 23/32” sand pine plywood and eight 3/8” holes, four along either end where the linkage attached, were measured and drilled with counter bores to attach the linkage mounting bracket. The positions of the holes were spaced evenly based on the

placement of the slots in the slotted steel angle plate that was to be used as the bracket to connect the sliding plate to the linkage as seen in figure 24. This bracket was an improvement from the original bracket design to improve the integrity of the bracket and help minimize any bending in the sliding plate when the die pressed.

Figure 24: Modified stainless steel mounting bracket and pin for the sliding plate.

Using roofing nails two slotted angled steel plates were attached to the sides of the sliding plate so that they provided a track to slide in the 1/4” plywood board that had the die attached to it. These supports can be seen in figure 25 bellow.

Figure 25: Modified die support design with stainless steel elbow brackets.

With the slider plate complete next the die blade was cut and sharpened. A 1”x3’-12G Flat Steel plate was used to make the blade and the blade was cut so the blade decreased with a constant slope of 1/2” for every 6”. This blade was then sharpened using an angle grinder. The final blade result can be seen in figure 26.

Figure 26: Cut and sharpened die blade from a 1 in X 3ft 12 gauge stainless steel bar

This blade was then easily bent by hand using the sole of a shoe as a mold to form the blade to, seen in figure 27. The extra blade material was grinded off and the connection welded together to finish the blade. The die then needed to be attached to a plate to that the die was centered to match up with its opposing die track. A plate was cut to the size of the slider plate from 1/4” plywood. Tacked to this was a thin sheet of metal to prevent the die from cutting into the plate when pressed. The die was to be welded to the metal sheet in a centered location to match with its opposing cutout.

Figure 27: Hand shaped stainless steel die blade.

To make the opposing cutout, the inside of the cutting die was traced and the shape was cut out of 23/32" plywood with a jig saw to provide a mold for the opposing die blade. A 1/8" x 1.5" x 3' steel flat with predrilled holes 3/8" from the bottom edge, was then molded by hand using clamps to the shape of the traced cutout, seen in figure 28. This blade was screwed to the wood cutout using 1" screws. A second blade was formed to the shape slightly larger than the cutting die. These plates form a track that supports the rubber and prevents the rubber from bending under the blade and allows the top die blade to pass between to completely cut the rubber.

Figure 28: Pine cutout of the die blade, made to support the bottom and a 1/8in x 1.5in x 3ft steel flat plate formed to pine cutout by hand and screwed to the cutout to hold the form creating the mirror image of the upper cutting die.

The upper die is removable to allow for different size shoes to be replaced. The bottom die have multiple sizes without having to remove the bottom plate as seem in the modified picture in figure 29. This also improves the support of the rubber to be cut. Then the prototype is ready to be tested.

Figure 29: Picture of the bottom die which has multiple slots to allow for multiple sizes without removal.

[4.4] Cost Analysis

The total cost for the prototype was about $75, a breakdown of the prototype costs can be seen in appendix A. In building the prototype three large pieces of material where purchased that contributed to the costs and was used to build the design. The frame pieces were cut entirely from two 2x3x96" pine studs, the links were cut from a 23/32x24x24" and 1/4x24x24" plywood plates and the dies were made from 1/8x1x36" flat stainless steel. To estimate the difference in the cost with different materials the dimensions of the three main pieces were used to look up prices for the alternative material options from SpeedyMetals.com, the breakdown estimates can be seen in table 3 below. As can be seen in the table wood saves a great deal on costs.

Table 3: Design costs with alternative materials, starred are the material used for that application.

	Material Cost Estimates		
Design Component	Wood	Steel	Aluminum
Frame	$4*	$19	$70
Linkage	$13*	$90	$290
Die	-	$16*	$30

Since the design also depends on the weight of the material in addition to the cost the estimated weights for different materials can be seen in table 4. As a point of comparison the wood prototype was about 30 lbs and it was only reasonably light. So as seen comparing the weights an option like aluminum would be a reasonable replacement from the wood to improve strength but at the expense of greatly increased costs.

Table 4: Design weight with alternative materials, starred are the material used for that application.

	Material Weight Estimate		
Design Component	Wood	Steel	Aluminum
Frame	9 lbs*	20 lbs	13 lbs
Linkage	8.5 lbs*	40 lbs	23 lbs
Die	-	2 lbs*	1.5 lbs

[4.5] Testing

With the prototype built a variety of tests could be completed to test the design capabilities, not all of which discussed, however, were completed. Some of the first tests that were completed were basic motion tests to make sure the design slider moved the way it was supposed to. The motion of the links on the pins was surprisingly smooth. The motion of the entire linkage with the slider plate was a little rocky because the two drive links weren’t connected so the links didn’t necessarily have move together but when it came down to it this didn’t affect how the press performed in cutting the sample just made it difficult to place and remove things from under the plate. A couple locking mechanisms would be beneficial to hold up the slider plate when placing or removing a sample.

Another basic functional test was a cutting test. This was completed in a couple steps, when the die blade was first completely sharpened the blade was tested in a vice with tire sample to make sure the blade was sharp enough and so could be bent into shape. The second test was to test the actually machine cutting capabilities using the press and the die to cut through a tire sample. The results of this test can be seen in figure 30.

Figure 30: Rubber sample cut from the sidewall of a tire that was used to test the press prototype. The left two picture show the top of the sample and the right the bottom. This wasn’t a complete cut because the bottom die were not used, so the die was forced to stop when it fit the wood

Lastly, a test of the durability of the links and blades would have been conducted to make sure the links and blades would last multiple runs. This was not completed simply because not enough material

was available at the time. But it would simply be done by cutting multiple samples and ensuring the quality of the samples and making observations of the press motion and performance. A dropping and beating test would also be beneficial to ensure the design was a lasting investment.

[5] Conclusions

There is a desperate need for accessible, durable and affordable footwear in the rural villages of Kenya. Walking is the main mode of transportation for the majority of the population and the lack of footwear has left many disabled from injury, disease and deformities directly related to their lack of footwear. The goal of this project was to make footwear more accessible in these rural villages by designing a manual machine that a village could use to make their own sandals from industrial belt or recycled tires to sell and barter. On another level this project was also intended to create more jobs and sources of income to help raise these extremely poor Kenyans out of poverty.

There are many different approaches that could effectively increase an inputted load to cut out the sandals, however, to make this a sustainable machine that can be built and sold to a large number of villages the machine had to adhere to some very strict design criteria. This design had to be easily transportable for a person who doesn't own a vehicle, affordable enough a person who make less than a dollar a day and at the same time had be easily manufactured so it could be fabricated in Kenya. Based on these design criteria a double toggle linkage was chosen to increase a manually inputted load and a die was chosen as the cutting method. The toggle linkage provides an exponentially increasing mechanical advantage as the links approach a toggle position which allows for this press to easily stamp out a rubber sandal in a single cut. From basic weight and cost calculations a machine mostly made of wood greatly increased the affordability and portability of the design. So the viability of building the press of mostly wood was calculated using SolidWorks stress simulation, which calculated a minimum factor of safety of almost two, which means would not immediately fail. From prototype testing, the wood model was successfully able to cut a sample of tire.

Some further testing would have to be completed to test the durability of a wooden machine before it is decided to be the best option. The wood links could be swapped out for steel ones which would increase the durability but add significant weight and cost to the design. A possible solution to the portability issue with the metal linkages however, could be to add wheels to the design. Another design

aspect that could be improved upon is the number of cutting dies required. This current design requires two cutting dies for one pair of shoes which means there are potentially a lot of dies to carry and maintain. For this report the sandal sizing was like that for a flip-flop with basically small, medium and large sizes for men, women and children which would result in at least twelve different upper dies. Building the prototype, was found to provide the best method to really realize these design flaws.

[6] References

[1] Easterly, William. "Was Development Assistance a Mistake?" The American Economic Review Vol. 97, No. 2 (May 2007): p. 328-332. Google Scholar. Web. 15 September 2010

[2] Lubeck, Paul. "The Crisis of African Development: Conflicting Interpretations and Resolutions," Annual Review of Sociology 18 (1992): p. 519-540. *JSTOR*. Web. 1 June 2010

[3] Morgan, William B., Solarz, Jerzy A. "Agricultural Crisis in Sub-Saharan Africa: Development Constraints and Policy Problems," *The Geographical Journal* 160 (Mar. 1994): p. 57-73. *JSTOR*. Web. 1 June 2010

[4] Polak, Paul. *Out of Poverty*. San Francisco: Berrett-Koehler Publishers, Inc., 2008.

[5] Sachs, J.D., McAuthur, J.W., Schmidt-Traub, G., "Ending Africa's Poverty Trap," *Brookings Papers on Economic Activity* 2004 (2004): p.117-216. *JSTOR*. Web. 31 May 2010

[6] Scalvenzi, M., Grazia Francia, M., Costa, C., "Tungiasis: Case Report of a Traveller to Kenya," *Case Reports in Dermatology* (Sept. 2009): p 29-34. *Google Scholar*. Web. 04 November 2010

[7] Seidman, Ann, "The Need for an Appropriate Industrial Strategy to Support Peasant Agriculture," *The Journal of Modern African Studies* 24 (Dec. 1986): p. 547-575. *JSTOR*. Web. 31 May 2010

[8] Stevenson, Keri; Stallwood, Bethan, "Tire Rubber Recycling and Bioremediation: A Review," *Bioremdiation Journal* (2008): p. 1-12. Google Scholar. Web. October 2010

[9] "Emerging Technologies to Benefit Farmers in Sub-Saharan Africa and South Asia," *Committee on a Study of Technologies to Benefit Farmers in Africa and South Asia, Board on Agriculture and Natural Resources, Division on Earth and Life Studies, National Research Council of National Academies*. Washington, D.C.: National Academic Press, 2009.

[6.1] Patent References

[10] Alexander, H.S., Pfeiffer, F.B. U.S. Patent 1 975 219, 1934.

[11] Bright, O.L. U.S. Patent 2 387 876, 1945.

[12] Dudley, J. E. U.S. Patent 5 133 236, 1992.

[13] Farrell, Sr., W. U.S. Patent 4 338 840, 1982.

[14] Fujieda, Y., Takebayashi, H. U.S. Patent 5 744 169, 1998.

[15] Khadem, D. U.S. Patent 0 098 318, 2002.

[16] Jolliffe, W. C., Mandrich, S., Obukuro, K. U.S. Patent 5 054 351, 1991.

[17] Schmidt, P. U.S. Patent 4 363 450, 1982.

[18] Schmidt. R. H. U.S. Patent 4 805 507, 1989.

[19] Schutt, D. U.S. Patent 5 551 325,1996.

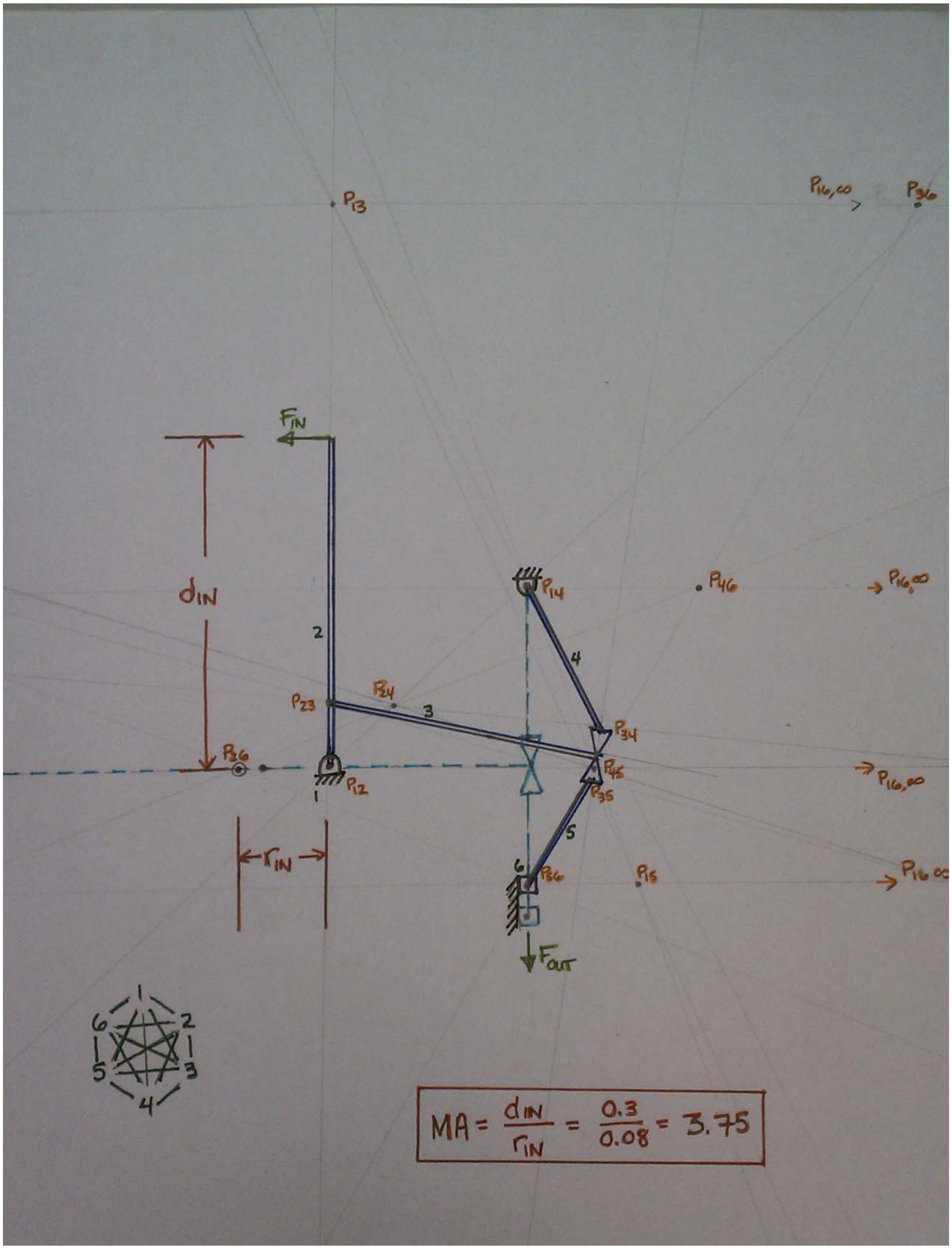
[20] Smithwik, Jr. J.M. U.S. Patent 5 881 620, 1999.

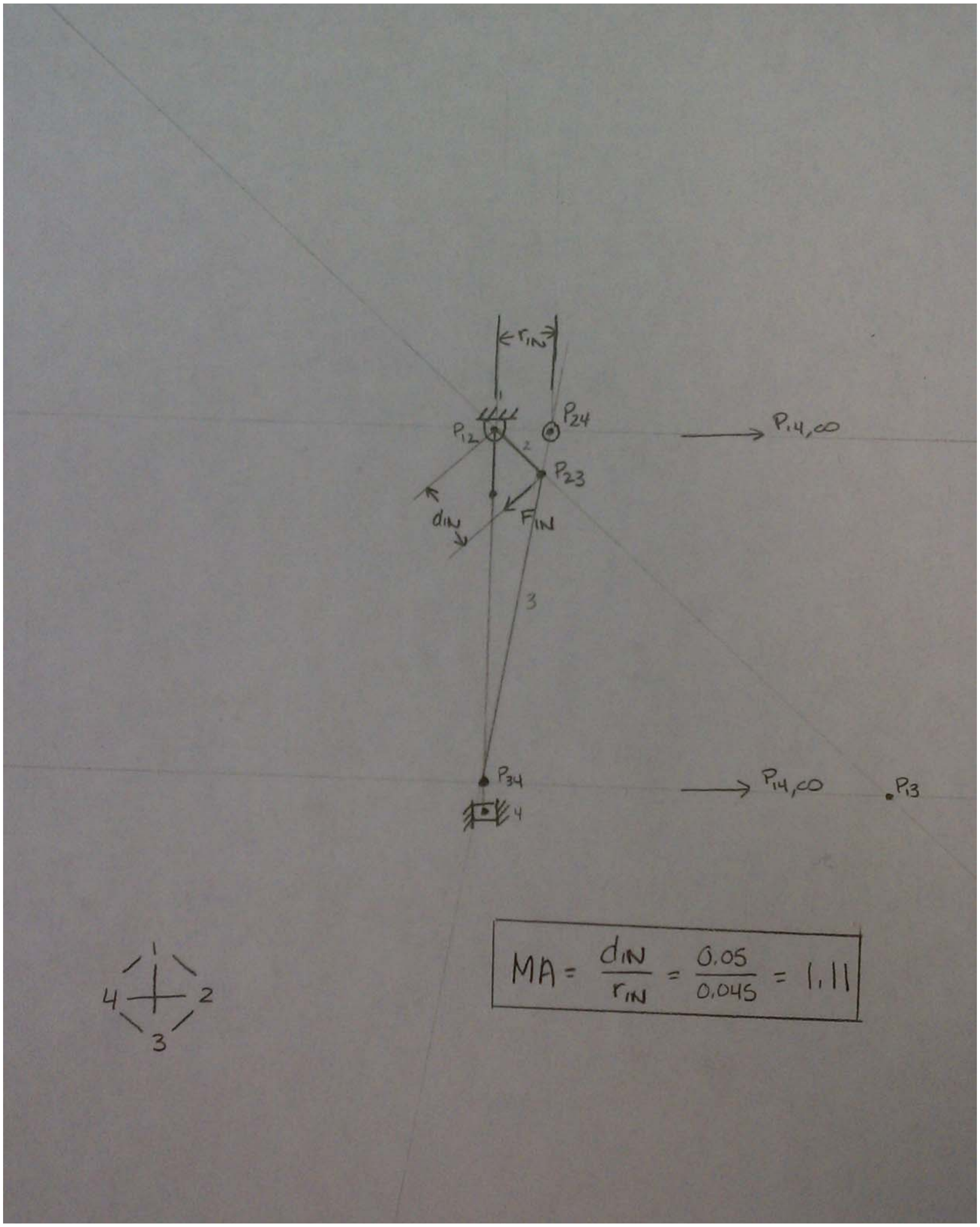
[21] Welch, J.W. U.S. Patent 5 750 196, 1998.

Appendix A: Prototype Materials

Function	Sub-Component	Materials	Quantity	Cost
Force enhancing mechanism	Frame	2X3X96" Multi-Purpose Stud	2	3.76
		5X1 13/16 Mending Plate	8	4.24
		6.5X1.5TZ DBL Plate	8	4.08
		3/8X3.5" Bolts	6	salvaged
	Links	23/32X2X2 Sand Pine Plywood	1	8.23
		3/8X2.5" Bolts	6	salvaged
	Misc.	Nuts	24	salvaged
		Washers	24	salvaged
Cutting Blade	Slider	1.25X1.25X36" Ang. slotted	1	5.97
		1/4X2X2 Sand Pine Plywood	1	5.23
	Slider-linkage bracket	Carr-Bolt 3/8X1.5"	8	2.72
		1.5X1.5X12" -14G Ang. slotted	2	5.94
		3/8"-3' Plate Steel Round	1	5.47
	Opposing dies	1X3-12G Flat Steel	1	4.58
		1/8 X 1.5 X 36" Flat Steel	2	11.72
		23/32X2X2 Sand Pine Plywood	1	salvaged
		1/4X2X2 Sand Pine Plywood	1	salvaged

Appendix B: Mechanical Advantage Calculations



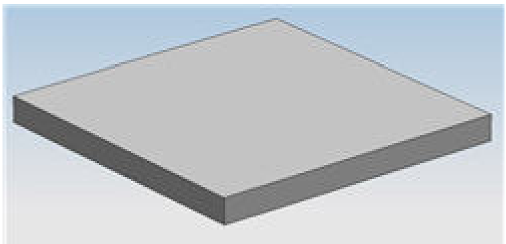


r_{IN}
P_{12}
P_{24}
$P_{14,\infty}$
P_{23}
d_{IN}
F_{IN}
3
P_{34}
4
$P_{14,\infty}$
P_{13}
4
2
3
$MA = \frac{d_{IN}}{r_{IN}} = \frac{0.05}{0.045} = 1.11$

Appendix C: Alternative Material Costs

From SpeedyMetals.com

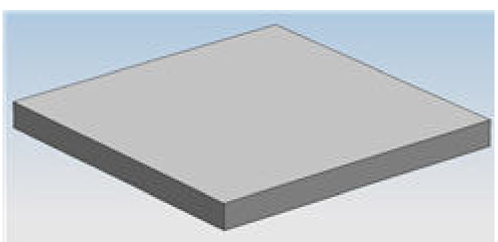
LINKAGES



1/2" 2024-T351 Aluminum Plate

2024-T351 Aluminum Plate
Dimensions:
1/2"
Material: Aluminum
Grade: 2024
Shape: Plate

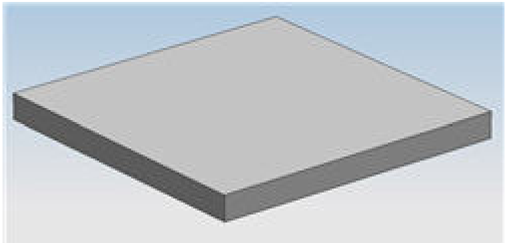
Product	Cutting Tolerance	Weight	Price
12"x12" Plate	Plus or Minus 1/4"	7.2720 lbs	**Price: $95.99**



1/2" 1045 Hot Rolled, Steel Plate

1045 Hot Rolled, Steel Plate
Dimensions:
1/2"
Material: Steel
Grade: 1045
Shape: Plate
Finish: Hot Rolled

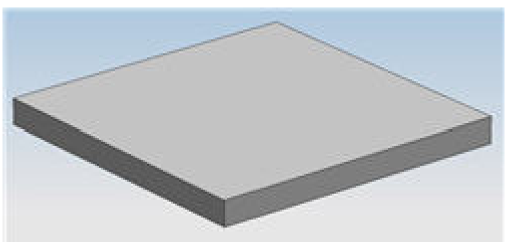
Product	Cutting Tolerance	Weight	Price
12"x12" Plate	Plus or Minus 1/4"	20.4192 lbs	**Price: $37.29**



1/4" 2024-T351 Aluminum Plate

2024-T351 Aluminum Plate
Dimensions:
1/4"
Material: Aluminum
Grade: 2024
Shape: Plate

Product	Cutting Tolerance	Weight	Price
12"x12" Plate	Plus or Minus 1/4"	3.6000 lbs	**Price: $47.52**

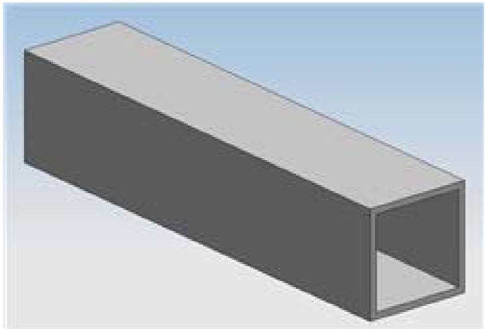


1/4" 1045 Hot Rolled, Steel Plate

1045 Hot Rolled, Steel Plate
Dimensions:
1/4"
Material: Steel
Grade: 1045
Shape: Plate
Finish: Hot Rolled

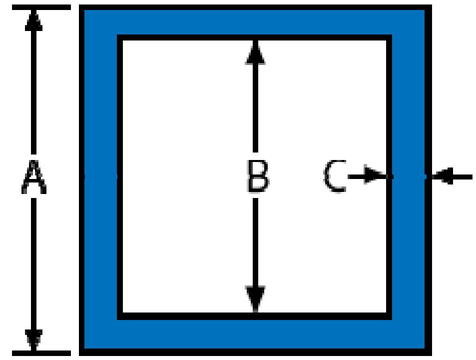
Product	Cutting Tolerance	Weight	Price
12"x12" Plate	Plus or Minus 1/4"	10.8000 lbs	**Price: $21.62**

FRAMES

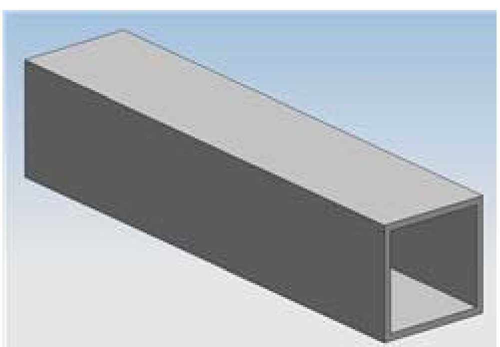


1-1/2" SQ {A} x 1-1/4" ID {B} x .125" Wall {C} Sq. Tube 6063-T52 Aluminum

Sq. Tube 6063-T52 Aluminum
Dimensions:
A: 1-1/2" SQ
B: 1-1/4" ID
C: .125" Wall
Material: Aluminum
Grade: 6063

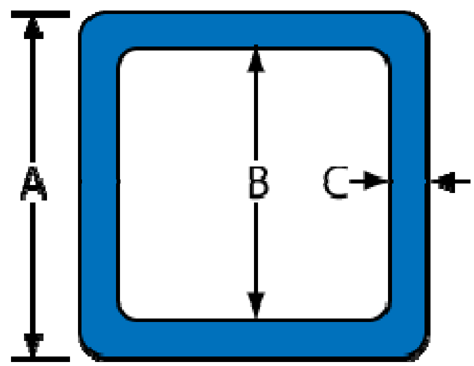


Product	Cutting Tolerance	Weight	Price
48"	Plus or Minus 3/4"	3.2016 lbs	**Price: $17.67**



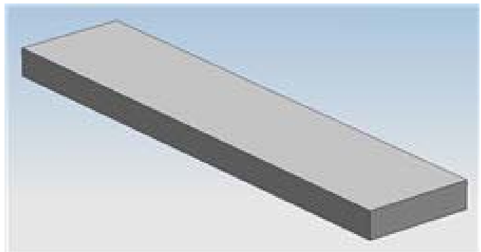
1-1/2" SQ {A} x 1.124" ID {B} x .188" Wall {C} Square Steel Tubing

Square Steel Tubing
Dimensions:
A: 1-1/2" SQ
B: 1.124" ID
C: .188" Wall
Material: Stee



Product	Cutting Tolerance	Weight	Price
48"	Plus or Minus 1"	12.9216 lbs	**Price: $15.88**

DIES

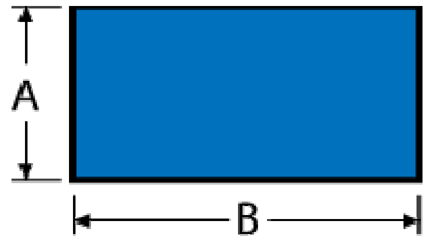


1/8" {A} x 1" {B} 2024-T4 Aluminum

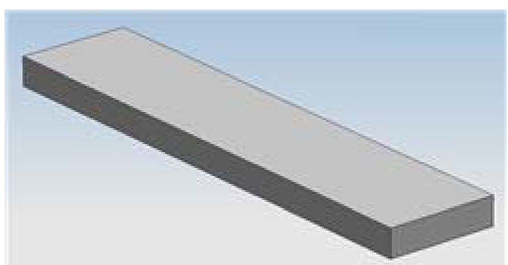
2024-T4 Aluminum

Dimensions:
A: 1/8"
B: 1"

Material: Aluminum
Grade: 2024
Shape: Flat



Product	Cutting Tolerance	Weight	Price
36"	Plus or Minus 1/2"	0.4536 lbs	**Price: $9.28**

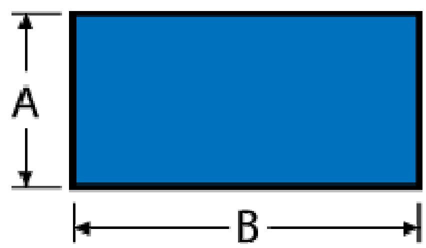


1/8" {A} x 1" {B} Cold Finished 1018

Cold Finished 1018

Dimensions:
A: 1/8"
B: 1"

Material: Steel
Grade: 1018
Shape: Flat
Finish: Cold Finished



Product	Cutting Tolerance	Weight	Price
36"	Plus or Minus 1/2"	1.2888 lbs	**Price: $4.08**

Appendix D: Material Application/Machining Research

From speedymetals.com

1045 Hot Roll Plate

C1045 hot roll plate is a silicon killed medium carbon steel. In the as-rolled condition, higher carbon content imparts increased strength over low carbon steels, such as 1018. 1045 hot roll plate is often stress relieved, normalized, or annealed after burning shapes to size to allow for easier machining. Response to heat treatment is excellent and the resultant mechanical properties which can be obtained permit wide usage in the production of machinery parts and shafts. Parts made from 1045 hot roll plate can be hammer forged, heat treated for further durability, or used in the non-heat-treated condition. Machinability is good, but forming and welding qualities are limited.

ANALYSIS

Carbon (C)	***Manganese (Mn)***	***Phosphorus (P)*** Max	***Sulfur (S)*** Max
0.42-0.5	0.6-0.9	0.04	0.05

1045 hot roll plate conforms to ASTM A830

MECHANICAL PROPERTIES

Condition	***Tensile Strength (PSI)***	***Yield Strength (PSI)***	***Reduction of Area***	***Elongation in 2"***	***Brinell Hardness***
As-Rolled	95,000	56,000	44	21	207

The above values are average and may be considered as representative of 1045 hot roll plate

APPLICATIONS

1045 hot roll plate has a wide variety of applications. It is used for machinery parts, excellent for die forging and hot upsetting, gears, bolster plates, base plates, wear plates, brake dies etc. 1045 hot roll plate can be flame cut to various shapes for a multitude of uses, both in the hardened or annealed condition. Can be hammer forged. 1045 can be used where greater strength is required than can be obtained from the lower carbon steels. It responds to heat treatment, and a wide range of properties can be obtained. In thicker sections, partial hardening increases strength substantially, and flame or induction hardening produces a high surface hardness.

MACHINEABILITY AND WELDABILITY

Machinability is rated at 64% of B1112. Average cutting speed 95 ft/min. 1045 is not readily welded, due to its higher carbon content. On thin sections, arc or gas welding can be used without preheating, but in welds and joints on thicker sections, preheating is necessary. Stress relieving after welding is also recommended.

HEAT TREATING

1045 is a water or oil quenched metal. The recommended quenching temperatures are 1550° F for water and 1575° F for oil. A wide range of mechanical properties can be obtained by tempering at different temperatured between 700° F and 1300° F Tempering below 700° F should be avoided. 1045 can be flame or induction hardened, but not recommended for carburizing or cyaniding treatments.
Normalizing: 1600° - 1700° F
Annealing: 1400° - 1500° F
Hardening: 1475° - 1550° F
Camber
Permissible camber for sheared and Gas-Cut A36 Plate, All Thicknesses:

Maximum Camber (Inches) = 1/8" x (Number of feet of length / 5)
Flatness
For all plates, the longest dimension is considered the length, and flatness tolerance along the length should not exceed the amounts indicated below the specified width and thickness in plate though 12' in length or longer. The flatness variations across the width should not exceed the tabular amount for the specified width

303 Stainless Steel Plate

303 is an â€œ18-8â€ chromium-nickel stainless steel modified by the addition of selenium or sulphur, as well as phosphorus, to improve machinability and non-seizing properties. It is the most readily machinable of all the chromium-nickel stainless grades and has good corrosion resistance, although less than other chromium-nickel grades, such as 304 or 316. It is non-magnetic in the annealed condition and not hardenable by heat treatment. Tensile strength and hardness can be increased by cold working. Slight magnetism can be detected by cold working. 303 has excellent scale resistance at temperatures up to 1600Â° F in continuous service. It is manufactured by the electric-furnace process and meets the exacting requirements of the aircraft industry.

ANALYSIS

Carbon (C) Max	*Manganese (Mn) Max*	*Silicon (Si)*	*Silicon (Si) Max*	*Chromium (Cr)*	*Nickel (Ni)*	*Molybdenum (Mo) Max*	*Cobalt (Co) Max*	*Phosphorus (P) Max*
0.15	2	0.15-0.35	1	17-19	8-10	0.75	0.75	0.15

Stainless Plate conforms to ASTM A895, SAE J405

MECHANICAL PROPERTIES

Tensile Strength (PSI)	*Yield Strength (PSI)*	*Reduction of Area*	*Elongation in 2"*	*Brinell Hardness*
85,000-95,000	30,000-40,000	50-60	45-55	160-180

The above values are average and may be considered as representative of 303 stainless

APPLICATIONS

303 is used almost exclusively for parts requiring machining, grinding, or polishing where good corrosion resistance is also required. Itâ€™s non-seizing and non-galling properties make it ideal for moving parts. Being austenitic steel, it is useful where low magnetic permeability is desired. 303 has fairly good forming properties. Used for aircraft parts, valves, valve trims, all types of screw machine products, bolts, screws, and machine parts, as well as architectural purposes. It is not recommended for vessels containing liquids or gases under high pressure.

MACHINEABILITY AND WELDABILITY

Machinability is rated at 78% of B1112. Average cutting speed 130 ft/min.
303 has only low to fair welding properties.
303 can be forged between 2100°-2350° F. Do not forge below 1700° F.

HEAT TREATING

303 is not hardenable by heat treatment. Cold working increases tensile strength and hardness.
Annealing range is between 1850° and 2050°F. Cool rapidly. Water should be used for heavier sections; air for lighter sections. The stress relieving range is between 400° and 750°F.

4140 Annealed Cold Roll Steel (ALLOY)

4140 cold finished annealed is a chromium-molybdenun alloy steel that can be oil hardened to relatively high hardenability. The chromium content provides good hardness penetration, and the molybdenum imparts uniformity of hardness and high strength. Through variations in the method of heat treating 4140, an exceptionally wide range of properties can be attained. For this reason, it is often used as stock for forging, as 4140 has self scaling properties. 4140 responds readily to heat treatment and is comparatively easy to machine in the heat treated condition. 4140 resists creep in temperatures up to 1000° F and maintains its properties even after long exposure at these relatively high working temperatures. Other desirable properties include good wear resistance, excellent toughness and good ductility in the quenched and tempered condition. 4140 cold finished annealed is available in rounds, squares, rectangles and hexagons. 4140 cold rolled rounds is also available with an addition of .15-.35 lead (41L40), which improves machinability (77% of 1212, surface cutting speed 127 ft/min) without sacrificing other desirable properties, with the exception that the use of 41L40 is not recommended for applications above 400°F, since at elevated temperatures, ductility in 41L40 is low.

ANALYSIS

Carbon (C)	*Manganese (Mn)*	*Silicon (Si)*	*Chromium (Cr)*	*Molybdenum (Mo)*	*Phosphorus (P) Max*	*Sulfur (S) Max*
0.38-0.43	0.75-1	0.15-0.35	0.8-1.1	0.15-0.25	0.035	0.04

4140 cold roll bars conforms to ASTM A322; ASTM A331; ASTM A304

MECHANICAL PROPERTIES

Condition	*Tensile Strength (PSI)*	*Yield Strength (PSI)*	*Reduction of Area*	*Elongation in 2"*	*Brinell Hardness*
Annealed	70,000	60,000	45	20	200

The above values are average and may be considered as representative of 4140 cold rolled annealed

APPLICATIONS

4140 can be used for as wide variety of applications where greater toughness and wear resistance is needed over lower carbon grades. Typical applications include strippers, holder blocks, mold bases, ejectors, back up and support tooling, fixtures, jigs, molds, cams, drill collars, bolts, stubs, couplings, reamer bodies, axles, shafting, piston rods, rams, hydraulic machinery shafts, gears, sprockets, gear racks, valves, chain links, spindles, tool bodies, tool holders, tie rods, boring bars, guides, tracks, ways, slides, wear strips or parts, forming dies, brake dies, trim dies, bolsters, machinery parts and components, etc. This material roll threads, knurls, and may be plated.

MACHINEABILITY AND WELDABILITY

4140 has a machinability rating at 66% of B1112. Average cutting speed 110 ft/min. 4140 is difficult to weld, but can be welded by any of the common welding practices providing section is preheated, and stress relieved after welding. 41L40 not recommended due to the fumes produced with the addition of lead.

HEAT TREATING

4140 has a hardening range of 1525° -1625° F. Quench in oil. A wide range of mechanical properties can be obtained by tempering between 400° and 1300° F.
Forging
Heat to 2100° to 2200° F
Normalizing
Heat to 1600° - 1700° F. Cool in air. Average BHN 285
Annealing
Heat to 1450° - 1550° F. Cool slowly in furnace. Average BHN 187

2024 Aluminum Plate

2024 is a high strength aluminum alloy with higher strength than 2011, with adequate work ability. With its high strength and excellent fatigue resistance, it is used to advantage on parts and structures where a good strength-to-weight ratio is desired. 2024 is readily machined at high speeds and gives accurate machining detail with a high finish. 2024 in the annealed condition is easily formed and may be subsequently heat treated. 2024 has good stress corrosion cracking resistance. Since corrosion resistance is relatively low, 2024 is commonly used with an anodized finish or in clad form, with a thin surface layer of high purity aluminum for increased corrosion resistance. Electrical conductivity is 35% of copper

ANALYSIS

Manganese (Mn)	***Silicon (Si)***	***Chromium (Cr)***	***Copper (Cu)***	***Iron (Fe)***	***Zinc (Zn)***	***Aluminum (Al)***	***Magnesium (Mg)***	***Other (Oth)*** *Each/Total*
0.3-0.9	0.5	0.1	3.8-4.9	0.5	0.25	0	1.2-1.8	0.05/0.15

2024 Plate Conforms to ASTM B209, AMS 4035, QQ-A-250/4

MECHANICAL PROPERTIES

Tensile Strength (PSI)	***Yield Strength (PSI)***	***Shear Strength (PSI)***	***Elongation in 2"***	***Brinell Hardness***
68,000	47,000	42,000	20	120

The above values are average and may be considered as representative of 2024 Aluminum Plate

APPLICATIONS

2024 is commonly used for structural components, couplings, hydraulic valve bodies, fuse parts, gears and shafts, worm gears, pistons, rectifier parts, missile parts, munitions, fasteners, cap nuts, bolts, hardware, truck wheels, transportation industry parts, computer parts, clock parts, veterinary and orthopedic equipment, and commonly in the aircraft industry for aircraft fittings, fuselage structurals, wing tension members, shear webs and ribs and structural areas where stiffness, fatigue performance and good strength-to-weight ratio is required..

MACHINEABILITY AND WELDABILITY

2024 in the T351 condition has a machinability rating of 90% when compared to 2011 at 100%. Machines to a high finish. 2024 is can be formed in the annealed condition. 2024 can be forged or hot worked, however subsequent heat treatment is necessary in order to retain reasonable corrosion resistance. 2024 is a very poor choice for welding. Gas and arc welding is not recommended. 2024 can be spot welded or seam resistance/flash welded. Brazing and soldering is not recommended. Generally welding should be

avoided because of the degradation of corrosion resistance that occurs as a result of the weld heat.

HEAT TREATING

2024 is an age-hardening aluminum alloy and responds to heat treatment to accomplish the strengthening (aging). The T4 condition is attained by a 920°F heating followed by a cold water quench and aging at room temperature. T6 is attained by the same 920°F and quenched followed by a 375°F for 10 hours and air cooling.

Cast Iron

Class 40 Gray Iron is a ferrous foundry metal that has been alloyed with carbon and silicon. Carbon is added to the base melt in amounts that exceed the solubility limits in iron and precipitates out as graphite particles. Silicon is added to the melt to nucleate the graphite which optimizes the properties of cast iron. Free machining characteristics are obtained by the graphite particles in the material. Class 40 Gray cast iron combines good strength with close-grain structure and has good machinability. Often dismissed as a cheap, dirty, brittle metal; cast iron is getting much more attention and use today because of its machinability, light weight, strength, wear resistance and damping properties.

ANALYSIS

Carbon (C)	***Manganese (Mn)***	***Silicon (Si)***	***Phosphorus (P)*** *Max*	***Sulfur (S)*** *Max*
2.6-3.75	0.3-0.65	1.8-3	0.12	0.07

* Carbon and Silicon targets are specified for each bar size produced in order to control size and shape of graphite flake Class 40 Gray Cast Iron conforms to ASTM A-48-64 Class 40

MECHANICAL PROPERTIES

Tensile Strength (PSI)	***Brinell Hardness***
40,000	207-269

Micro-Structure: Essentially Pearlitic Compressive Strength (Min PSI): 150,000
Deflection Strength**: 2600 **Average pounds load on 1.2 bar 18" span

APPLICATIONS

Class 40 Grey Cast Iron has a wide range of uses, including fluid power glands, manifolds, pistons, spools, valves, bushings, cams, gears, gibs, pulleys and wheels, rams, sheaves, side frames, slides and ways, cylinder liners, shock absorbing pistons, valve guards, rollers, rotors, seals, aluminum mold plates, chain sheaves, core boxes, dies, pattern plates, augers, screw conveyors, screw washers, pump components, etc.

MACHINEABILITY AND WELDABILITY

Machinability of Class 40 Gray cast iron is good with average cutting speeds at 700 sfm and finishing speeds as high as 1,400 sfm.
Weldability is considered fair to poor as compared to low carbon steels.

HEAT TREATING

Normalizing
Gray iron is normalized by being heated to a temperature above the transformation range (1625°-1700°F), held at temperature for about 1 hour per inch of maximum section thickness, and cooled in still air to room temperature. Normalizing is used to enhance

mechanical properties, such as hardness and tensile strength, and to restore as-cast properties that have been modified by another heat treatment, such as graphitizing and pre and post-heating associated with welding.

Heat Treatment

Gray Iron can be hardened from 1575° and oil quenched to attain 50 Rockwell C minimum surface hardness. Hardness will lessen towards the core.

TOLERANCES

Rounds are produced in an oversized condition.
Flats and squares are produced virtually on size, and will finish approximately 1/4" below produced size.