Magnesium Wrought and Fabricated Products
Yesterday, Today, and Tomorrow

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Abstract

The developers of magnesium metal production were always interested in methods of producing alloys and products. Casting was the first major development in the production of structural parts, but rolling, forging and extrusion closely followed it. This paper reviews the tremendous historical developments in wrought products during the 1930's and 1940's. At the peak of magnesium production for World War II, thousands of tons of magnesium sheet were produced each month and fabricated into aircraft parts. Several aircraft were made of all magnesium extrusions, sheet and castings. These included the German Arado 196 and the US XP56 and F-80. Many other aircraft used large quantities of rolled magnesium. Most of the magnesium was produced on rolling mills developed for other metals until Dow built the large magnesium fabrication mill at Madison, Illinois (Owned and operated today by Spectrulite Consortium). Brooks and Perkins also fabricated magnesium parts and built a rolling mill in 1952.[1]

Explanation of Subject Development

The purpose of this paper is not to explore the metallurgical details of the effects of the various wrought processes that can be applied to magnesium. It can be seen by doing a very cursory review of the magnesium processes that some of the apparent disadvantages can be turned into advantages if properly understood and exploited. Things like the marked capacity of magnesium for preferred orientation can be exploited in certain forged pieces. The paper will review the past and some developments of wrought products for information purposes.

Introduction

Magnesium metal has been used in a number of structural applications for many years. The vast majority of those applications have been as castings. After magnesium was put into commercial production, the main uses were pyrotechnic. It was not until Dr. Pistor and German researchers developed melting fluxes that magnesium parts could be made that would withstand exposure to corrosive atmospheres. Castings were the main focus of attention by the main producers of magnesium in both the US and Germany.[2]

It was after 1930 before much work was done with rolling and forging and extrusions of magnesium. The work of the Italians in Northern Italy was the first substantial effort to use the light magnesium parts (with castings) in aircraft[3]. The Germans watched, visited and learned rapidly. As the German government was reorganized in 1933, industry took steps to develop magnesium. Immediately steps were taken to design and produce parts that were incorporated into the construction of vehicles, airplanes and rockets.[4]

With the start of defense plant activities in the US, many companies installed magnesium wrought product operations. This was with direct government support, first from the Defense Plant Corporation, and later from the Wartime mobilization budgets.[5]

Many companies in many countries developed magnesium fabrication techniques and trained craftsmen during the wartime periods. After the war was over, many of the wrought product producers went out of business due to the dropping of government support.

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Dow continued in a lead role, with a number of other companies working hard to adapt the plants and knowledge of military products to peacetime. Some military programs in rolling and extrusions helped some businesses stay in operation. However, many companies tried to develop magnesium sheet and extrusions for boats, canoes, archery equipment, skis, ski boots, pianos, harps, delivery truck bodies, truck cabs, buses, trash collectors bins, racing boat hulls, private aircraft parts, fire truck hose containers, material handling equipment, dock boards, portable ramps, aerospace equipment parts, including rockets and satellites, radar tracking systems, electronic equipment cabinets, vibratory screens, tote bins, luggage frames and sides (Samsonite), ladders, water heater anodes, typewriters, rocket launchers and mortar bases, textile machinery parts, concrete buckets and hand finishing tools, jigs and fixtures and vibration testing machines.[6]

However, the increase of price of magnesium in the 1970's had the effect of killing many of the smaller operations, and seriously affected the larger operations. Only in the past few years has there been a large scale, global interest in developing wrought products. This time it is led by private industry and hopefully will be more permanent than the previous efforts.

History

The history of magnesium from a curiosity metal to an industrial material was greatly influenced by wars. While the Germans were developing magnesium production and uses in the early 1900, they also were spurred along by the need for magnesium in the military.

In 1915, the effects of World War I caused a shortage of magnesium metal, powder for flares and tracer bullets. The price of the product was \$5.00 to \$6.00 per pound. Eight companies in North America went into the production of magnesium metal. General Electric built the first magnesium plant in the United States in 1914 at Schenectady, New York. The military requirements for World War I stepped up total world production to an estimated 3000 tons per year. Immediately after the war, the production dropped to less than 400 tons per year. As soon as the war ended in 1918, the number of companies dropped off to two in the US, Dow Chemical and Alcoa's American Magnesium Corporation. Dow researchers developed a special electrolytic process using a "wet" feed, 72% magnesium chloride ($MgCl_2 \cdot 1.5H_2O$). Dow fed the "wet" material into a specially designed cell that required continual replacement of the carbon electrodes. This eliminated the problem of getting fully anhydrous magnesium chloride, but it produced an operation that required a higher level of manpower to tend the cells on a daily basis.[7]

American Magnesium Corporation (1920-1928) used the modification of the aluminum electrolysis process, which had been developed by Harvey [8]. A large steel cell was filled with a molten bath of fluoride material and magnesium oxide was dissolved in this bath and electrolyzed to produce magnesium metal with oxygen as a by-product. The reaction temperature was 900-1000 °C. While current efficiencies were 50%, the energy efficiency was 10%.

In Britain, in 1914, Johnson, Matthey and Co and Vickers, built a magnesium production plant using the sodium reduction of fused anhydrous magnesium chloride. This plant made magnesium powder, wire and ribbon required for pyrotechnics. The plant was closed in 1920.

In late 1915, French Societe d'Electrochimie built a magnesium plant at Clavaux, Isere, which extracted magnesium from magnesium chloride by the electrolytic process. In 1916, the plant produced 25 metric tons. In 1922, the Compagnie Alais, Proges et Carmargue, now Pechiney, erected a similar plant at Epierre, in Savoie.

In Canada, magnesium was made by Shawinigan Electro-Metals Company at Shawinigan Falls, Ontario in 1915. In 1918, the plant was the largest producer in North America with a daily output of 300-400 kgs per day. The plant operated until 1919 and was closed down.[7,3]

The Russian technical and mining community was investigating and working to develop the potassium-magnesium salts that were located in the Perm region near Solikamsk. All new kinds of military uses for magnesium were becoming known. In 1915, the specialists of the Petrograd Electro-Chemical Institute went to work on a project commissioned by the South Ural joint stock company, Magnesite, to extract magnesium from magnesite. The technical team quickly realized that the carnallite, also available in the same area, was a more appropriate material. Several kilograms of magnesium were produced in 1914-1915 at Petrograd Polytechnical Institute. It is recognized that the founder of magnesium metallurgy in Russia and of a national school of electro-chemists was Pavel Pavlovich Fedotyev.[10]

Total annual wartime production of magnesium for all countries may have reached 3000-5000 metric tons. After the war, the production quickly dropped off as many of the wartime subsidized producing companies left the business.

Between the Wars

When the wartime requirements stopped, the ability to produce magnesium and sell at a profit also stopped for many of the newer companies in all countries. So most of them, especially in the US, closed and went out of business.

Most magnesium was used in pyrotechnics until the basic problems associated with producing castings (and other fabrications) were overcome. The property that made magnesium attractive for flares and tracer bullets created great problems in the foundry. Magnesium tends to oxidize readily when molten. Hence the melting of magnesium alloys in an open crucible caused burning on the surface of the molten metal and the oxides formed would become inclusions in the sand castings made from the metal dipped from the crucible. Sand castings used water to bond the sand and this water would react with the magnesium giving burnt spots on the casting surfaces.

A German magnesium research group working at Bitterfeld discovered that carnallite salts could protect the surface of the melting magnesium[2]. This cover flux also gave a refining action when stirred into the melt. Fused salt flux mixtures were designed and used to absorb the oxides, nitrides and chlorides. This step was discovered in 1925 and it gave a process to produce very high quality castings without inclusions. (Entrapped foreign particles}. Sulfur and other chemicals were added to the sand to suppress the reaction with the moisture in the sand. Actual development of usable sand castings expanded commercially in the early 1920 period. After a long slow introduction, the use of magnesium in structural areas started as castings and grew to forging, extrusions, and rolled products, mostly in Germany. The development of magnesium use did not expand rapidly until the military build up of World War II started and new areas of use continued through the war.

The magnesium industry in the United States consisted of Dow Chemical alone from 1928 until 1940. While Germany and Japan were building up their magnesium industries in the 1930's, the US and Canada were running pilot plants and looking at new technology. Henry J. Kaiser, the noted American industrialist was building a carbothermic magnesium plant in California. The plant used seawater magnesia (MgO) and coke as a reductant.[7,9] Dow continued to operate their original electrolytic magnesium plant in Midland, Michigan. This plant used brine for the feed stock. In 1940, Dow also built a plant to produce magnesium from seawater in Freeport, Texas and operated this plant until December of 1998. The first production of magnesium from seawater was in Great Britain in March 1940 when Magnesium Elektron used seawater magnesia to produce magnesium chloride.[9]

Germany had been the first into commercial electrolytic magnesium production. They continued research on this and on other magnesium production processes including the use of FeSi to reduce calcined dolomite. There was also extensive experimentation to develop the fabrication technologies, including sand casting, die casting, forging, extrusion and rolling. New alloys of magnesium were worked on to improve the properties of the metal. A complete summary of all the knowledge available about magnesium was published in 1939 in a book titled "Technology of Magnesium and its Alloys", by Adolf Beck. It was translated into English by F.A. Hughes in 1940.[2]

Early Wrought Product Development

The use of flux enabled the production of sound castings. It also enabled the production of large shapes that had few inclusions. This encouraged the production of magnesium alloy billets that could be forged. The first wrought products that were developed for commercial use seem to have been forgings.

In the 1919-1921 period the use of magnesium for pistons for internal combustion engines was developed. This was done both by Dow and by several companies in Germany. One small listing suggested that in 1927, Alderwerke in Frankfurt, Germany developed an automobile using the most advanced magnesium cast and forged parts. It was also mentioned that the Italian company, Isotta Fraschini, made the first serious efforts to incorporate magnesium into aircraft. In 1926 ,it was said that they started producing magnesium parts in Milan, by casting and forging.

The next area of wrought magnesium usage in aircraft was in fuel tanks and later propellers. Starting in 1930 and continuing in 1932 and 1934, special light planes participated in a Round Europe flight. In 1930, 25 of 31 engines used magnesium crankcases and 28 had magnesium fuel tanks. Later flights saw most aircraft equipped with magnesium propellers. The Italian Breda engines used many magnesium parts. The Round-Europe aircraft has a maximum allowed empty weight of 400 kilograms.

In 1931, the first trans Atlantic formation flight led by Italo Balbo flew from Orbetello, Italy to Rio de Janeiro. Fiat engines were used on the 14 SM.55 flying boats. In 1933, the same type of aircraft was used in a 25 plane formation which flew from Orbetello to Chicago's Century of Progress Fair.[11] Isotta Franschini engines on these planes used many magnesium parts. There were housings of magnesium, propeller shafts, oil sumps, distributors, oil tanks, carburetor housings, etc.

In 1934, the Italian pilot Donati flew to a world record altitude of 14,335 meters (47,000 ft) in a Caproni 113 which had magnesium gas and oil tanks and used magnesium in its body surfaces. The French pilot, Raymond Delmotte established a land speed record of 502.5 km/hr (310 mph). His Caudron 460 had magnesium engine cases, body surfaces, fuel tanks, seats, fittings, wheels, oil pump, carburetor and several other parts.

The British de Havilland Comet flew to Australia in 71 hours. It used more magnesium than any other British aircraft. The crankcases and other parts of its twin Gypsy VI engines used magnesium. The under carriage, wheels, instrument panel, control lever, seats, wheel fairings, nose piece, front and rear engine cowlings and wing fairings were also all magnesium.[12]

Jean Piccard and his wife made an ascent at Dearborn, Michigan in 1934. Using a balloon carrying an 8 foot in diameter spherical magnesium gondola, they reached an altitude of 17,550 meters (57,564 ft.). In 1935, another balloon ascent by Stevens and Anderson, using a similar large magnesium gondola, reached an altitude of 22,066 meters (72,376 ft). The gondolas were fabricated from heavy flat magnesium plate, cut in an "Orange Peel" configuration and heated and welded into a sphere.[5}

German Wrought Product Development

The Germans had the world's largest magnesium production potential and all of these fabrication happenings were not lost on their designers. Magnesium developments began to happen after the German government was reorganized in 1933.

Technical Review and Operations. H. Altwicker[4] quickly summarized the basic problems with magnesium wrought product production. He said that the number of slip planes within a single crystal largely determines the capacity of a metal for plastic deformation by extrusion, forging or rolling. This is because the degree of ductility found in metal under plastic deformation increases with the number of available slip planes in the individual crystals. It is well known that the hexagonal magnesium crystal exhibits fewer slip planes than crystals of metals that crystallize in more highly symmetrical forms. Conditions for the plastic deformation of magnesium and its alloys are therefore relatively unfavorable, and closer limits must be observed in respect of such fundamental factors as temperature, degree and speed of deformation, etc, than are necessary with more easily worked metals such as iron, copper and aluminum.

German Aircraft Usage

Altwicker[4] mentions that in 1929, a single engine training plane was built in which magnesium was used for all sheet, extrusion, and tubing material. In particular, the wing beams and wing ribs, the fuselage, including the sheet cowlings, the rudders and controls were made of magnesium. This plane may have been in the Round Europe competition. It was said that in 1939, it was still being flown.

Many magnesium parts were designed and used in aircraft production. Of course, the original production was for civilian aircraft. Many of the original civilian aircraft, particularly the Focke Wulf Condor 200, became vital parts of the military air service. The Condor used magnesium sheet for the engine cowlings, lower covering of fuselage and wings, the transitional fairings between the wing and tail unit, as well as the fuel tanks and several other fairings. The parts are partly riveted and partly welded. The original civilian passenger plant model used seats made from welded Elektron (magnesium) tubes. The total weight of magnesium alloys used in the Condor was 650 kgs (1430 lbs) of which over 500 kg (1100 lb) were magnesium sheet. This was primarily AM503 alloy that was considered to be the most weldable of all light metal alloys.[15]

The prewar Arado 196 was called an "all magnesium" aircraft. It was a sea plane made to be launched from battleships. It was also used in reconnaissance duty from shore-based airfields. The Messerchmitt 109 used forged Elektron (magnesium) AZ855 engine bearers (mounting brackets). Several other Messerschmitt liquid cooled engines used this type of mounting bracket. The magnesium forging concept was used in several other engine mounts. The Focke Wulf 190, which had a BMW 801D radial engine, used magnesium mounting brackets. The 801D engine also used 20 kg (44 lb) of magnesium forgings. Both Messerschmitt and Focke Wulf used magnesium sheet in their airframe construction.

Heinkel used 80-100 kg (176-220 lb) of magnesium in the airframe of the HE-111. The HE-177, 4 engine bomber used 400-500 kg (880-1100 lb) in the airframe in the form of castings, forgings and sheet. Junkers was the largest used of magnesium in Germany for aircraft. The JU88A-4 (exclusive of engines) had over 350 kg (770 lb)of magnesium parts, of which 96 kg (211) were forgings. The company made extensive use of magnesium sheet and forgings. Prof. Hertel, Junkers design chief, was a pioneer and leading exponent of magnesium utilization in aircraft in Germany. He was responsible for the adoption of the forged magnesium engine bearers (widely used in German Aircraft) and advocated the use of magnesium to the exclusion of aluminum in all forgings for aircraft except those subjected to elevated temperatures, such as pistons. The forging of these parts and of magnesium propeller blades was originally done on a 7,000-ton press and in 1938, more presses were added, including a 15,000-ton press.[15]

Other German Wrought Products

In 1939, Altwicker [4] wrote a paper on German wrought products for the annual SAE meeting. He described the production of passenger carrying trailers by Waggonfabrik Uerdingen. The total weight of the trailer, ready for operation and with steel wheels, was 3400kg (7500 lb). It used large quantities of AM537 alloy. The weight of the body , which means the entire vehicle without wheels, axles and springs is (2270kg) 5000 lbs. By deducting from the body weight the weight of the interior equipment, a weight of 750kg (1650 lb) is obtained for the magnesium body. In spite of the relatively large weight of the unsprung chassis parts, a weight reduction of 26% was realized in this vehicle as compared to a standard trailer built from steel which weighed approximately 4590kg (10,100 lb).

Ultimately these trailers were used as troop transports by the military and gave an excellent performance. They also were very robust and many existed doing various duties for many years after the war.

Magnesium sheet was also forged into gun mounts for large guns. Made from magnesium AZM alloy, the large 2500mm (8.25 ft) long, 700 mm (2.3 ft) wide pieces (28kg –61.6 lb) were produced in one operation on a 15,000-ton press.

The overall maximum sheet production was in 1942, with an average monthly production of 300 tons. All magnesium rolling was done on antiquated, second hand equipment that contributed to inefficiency. The production was principally AM503 (80%), because they could not weld the higher strength alloys. Very little AZ31 was produced and the production of AM537 had only become semi-commercial when it was stopped due to shortage of Cerium. The remaining production was in AZM.

Penalties on German Magnesium Industry

There was a large US group put together to review the light metals industry in Germany. A draft report that was the basis for parts of the peace treaties signed was issued on 15 July 1945.[16] It was recognized that 60-70% of the aluminum produced in Germany went to military uses. More important it was found that a higher portion of the magnesium produced went to military uses.

It was felt that the German light metals industries should be controlled. The report stated, "Not only is German ingenuity in this field as great or greater than that of any other country, but there is a strong possibility that further important technical advances will be made in light metals after the war when engineering talents can once again concentrate on technical problems." From this basic concept the premise was developed for the banning of magnesium production and use in Germany as part of the treaties. This was known as the Use-Verbot.

The draft clause in the committee report suggested that the following wording be used, "The production of magnesium metal, and the fabrication of it into semi finished forms should be completely forbidden in Germany. All facilities and equipment should be removed. Research on the production, alloying, fabrication, and use of magnesium should be forbidden." A second recommendation said, "The productive capacity for and the use of magnesium chloride shall be limited to minimum domestic requirements for purposes other than the making of magnesium metal. All excess capacity should be removed or destroyed."

In regards to fabrication, a specific recommendation was made that said, "All equipment for the fabrication of magnesium, including casting, rolling, extruding, forging, drawing and powder-making should be forbidden." It was from this type of thinking that the US government acquired two large forging presses, the 14,000 ton extrusion press (installed and operated at the Dow Madison, Illinois mill) and some additional equipment.

Wrought Magnesium – United Kingdom

The UK had been very aware of magnesium and had developed a very good foundry industry in the prewar period. When the war started, examination of downed German aircraft revealed the heavy use of magnesium alloys. The resultant weight savings had given the aircraft a superior performance. Documents reveal the intense effort to expand magnesium production in the UK. Also, Dow was approached as they were expanding their plants and asked for 8 million pounds per year. Dow agreed and in the Freeport, Texas magnesium plant which was just being designed to use seawater for the magnesium supply, they added a British Alloy Corporation building to produce alloy for shipment from the Freeport harbor.[13]

Most of the fabricators of sheet, extrusions and forgings, were operating under license arrangements with Magnesium Elektron Ltd. MEL, as the producer, supplied to the fabricator the required shapes in the form of slabs and billets. Heavy scrap like sprues, gates, and risers was remelted in the foundries. Light scrap such as fine chips, saw dust, sheet fabrication scrap was returned to MEL.[14]

Only AM503 sheet was rolled in the UK. Rolling equipment was two-high and similar to the hot rolling and breakdown mills in the United States. Two-high rolls were used for finishing, whereas in the US, the trend is toward four-high mills. All breakdown operations were done hot, both the metal and the rolls being heated. Highly polished finishing rolls were used to give the finishing passes. This reduction was calculated to give 5% cold working.

Magnesium sheet was not heavily used for primary structures. Efforts to develop magnesium were in the area of fuel and oil tanks, seats and other accessories. Essex Aero made fuel tanks from magnesium sheet and extruded shapes ranging from 50 gallon to 2200-gallon tanks. This resulted in a weight saving of 1.2 to 1.4 pounds per gallon of capacity when compared to aluminum. In some of the larger planes, the saving was as much as 1000 lbs per plane. A premise was developed that a magnesium tank with bullet sealing would not weigh any more than a bare aluminum tank. Magnesium was considered to have advantageous properties in the event of puncture by bullets. It was said that the bullet cuts a clean hole that is more readily sealed by the covering than in the case of a more ductile metal that tended to flow or "tulip" with the travel of the puncturing object.

One aircraft company was interested in the use of magnesium sheet for control surfaces, fuselage coverings, ailerons, etc. There was little saving in weight, but construction could be simplified and skin surfaces produced that were much smoother and more rigid, thus improving airflow characteristics. Westland Aircraft was one of the most enthusiastic about the use of magnesium in the airframe. They were able to use 450 kg (1000 lbs) of magnesium, strip and castings in a structure weighing 2900 kg (6400 lbs). Applications for sheet were trailing edges, aileron and elevator coverings, fairings, undercarriage and gun bay doors, engine nacelles, rudders, elevators. In one model, the rear fuselage covering from the cockpit to the tail assembly was made of magnesium sheet.[14]

The majority of the work in the UK was directed to casting and more than 85% of fabricated products were used in the form of sand or permanent mold castings, going mainly into engines, airframes, aircraft wheels and accessories. There was little mention of extrusion or forging in the reports on the developments.

After the war, a special company , Planet Aviation Ltd produced a four-place airplane designed by Major J. D. Heeman, a consulting engineer from London. A true monocoque fuselage structure was designed used magnesum-zirconiuim sheet. At the same time, experimental monocoque wings for jet aircraft were tested.[14]

At the 1953 International Magnesium Exposition in Washington, an auto body made of magnesium was shown. Weighing 60 kg (150 lb), the body was set on a British-made Allard Chassis. It was produced in one piece. The car also had a magnesium fuel tank.

Wrought Products-United States

Dow became the sole magnesium producer after the Aluminum Company of America closed their American Magnesium production plant in 1927. Alcoa continued to experiment with magnesium fabrication and in new alloy development. Herbert Dow, ever confident that magnesium had a great future, started magnesium fabrication experiments. A 1200 ton extrusion press was installed in the Midland Metallurgy Lab. Extrusion experiments were run and many shapes were produced in production development. Dow then purchased a die casting machine and a small rolling mill for the Midland lab. The magnesium fabrication facility was used as a training area for fabricators and others in how to handle magnesium. By 1933, the expansion of metal fabrication activities required construction of a new building to house the new equipment and personnel.[13]

Herbert Dow[17] once said that any American manufacturer who hope to make money making and selling metallic magnesium had four very big jobs on his hands:

1. He must learn to manufacture the metal cheaply, so that it could compete in price with the traditional metals.
2. He must convince users of metal that they should use magnesium.
3. He must either discover and tell customers how to work the metal, or else work it for them. Inasmuch as unalloyed magnesium is worthless as a structural metal, this involved inventing a line of magnesium alloys and devising proper techniques for working each one.
4. He must do the job in competition with the powerful German Chlor-magnesium Syndikat, or Magnesium Trust,, which since 1907 had been working with magnesium, had already developed and patented a number of very good magnesium alloys, and knew how to fabricate them.

Eventually Dow established the Bay City, Michigan Fabrication plant, which started operations in 1934. Some of the first products were canoes from magnesium, truck and trailer bodies, extruded water heater anodes. Auxiliary projects included the development of a continuous direct chill process for the manufacture of rolling slabs and extrusion billets. By 1935, the use of magnesium in military aircraft in Europe had begun to escalate and magnesium exports from the US grew to help fill that demand. After 1935, the Dow production plant at Midland was doubled and a new site found for an additional 12 million pounds per year at another location.

The new plant was built in Freeport, Texas in 1940 and used seawater as the source of magnesium. [Note: A cubic mile of seawater contains 6,000,000 tons of magnesium metal] After the first metal was produced, the build up for defense of the US required increased magnesium supplies as well as magnesium that was shipped to Great Britain. The plant was doubled in the first year of operation.

The US government then set a goal to expand magnesium production to 300,000 tons per year and 14 new magnesium production plants were built.[7] Magnesium fabrication facilities were also built or contracted including sand foundries, die casting operations, extrusion plants and rolling mills. At the peak of operation, there were a number of 100% government-owned fabricating plants, including 8 sand foundries, 1 permanent mold foundry, 1 die casting foundry, 1 extrusion plant, and 2 forging plants. There was also government owned equipment installed in lessees' plants. These included 11 sand foundries, 1 die casting foundry, 1 extrusion plant, and 1 sheet and plate operation. Ford also built a very large magnesium foundry to support the building of engines for the B-24 bomber plant at Willow Run.

The US worked with extrusions and sheet during the war period. The most significant happening was R-40C, a Request for Data issued by the Army Air Corps in 1940. The request ultimately produced three prototype aircraft all built of magnesium. Three companies submitted acceptable proposals for three aircraft of different designs (all pusher engine designs). The Northrup XP-56 was the winner of the trials and rating contests. It was essentially a flying wing, with counter-rotating pusher propellers. It had the first all-magnesium alloy, all-welded airframe in history. Northrup had to develop heliarc welding to fabricate the magnesium fuselage and wings. The aircraft underwent it first flight tests in 1943. The program was not completed by the war's end and was cancelled.[18]

The Northrup XP-79B Flying Ram, was a rocket engined flying wing interceptor, with a heavy magnesium sheet usage. The magnesium wings had special ¼ inch case hardened steel leading edges. It was designed to fly into enemy bomber formations and slice off wings or tails and survive. It never went into production.[19]

The B-36 bomber was the magnesium wonder of the world. Design was started prior to the end of WWII and the development continued with the development of the largest bomber ever built. The gross weight of the production model was 162,727 kg. (358,000 lbs). It was the largest single user of magnesium sheet, with 50 per cent of the external skin using over 4000 kg (9,000 lbs). The model of the B-36 built utilized 5555 kg (12,200 lbs) of sheet, 700 kg (1,500 lbs) of forgings, and 300 kg (660 lbs) of castings. [20}

The B-36 was unique in that 25 per cent of the exterior surface of the plane was covered with magnesium skin which had its stiffeners attached with metal adhesive. In a wing trailing edge section, magnesium replaced an aluminum design that fatigue-cracked due to vibrations from the six pusher engines. 385 B-36 aircraft were built.

After the B-36 came the B-47 jet bomber. It had a total of 5500 kg (12,000 lb) of magnesium sheet, extrusions and castings. Magnesium was extensively used as a skin material on wing and tail leading edges, jet engine pods, and cowling, gun enclosures and for miscellaneous doors. The tail cone of the B-47 was fabricated primarily of magnesium with some aluminum. In the B-52, 1600 kg (3,600 lbs) of magnesium was used. 636 kg (1,400 lb) of sheet was used. The KC-135 jet tanker had 818 kg (1,800 lbs) total with 590 kg (1,300 lb) of sheet.

Extruded magnesium floor beams were first tried in the C-47 cargo planes. Later they were installed in the C-54's (DC-7). The Douglas C-124 Globemaster used magnesium for the main floor beams and also for the fold up second deck for troop transfer. The C-133 Cargomaster used ZK60B extrusions in the cargo deck and ramp. There were problems with these floors due to galvanic and other corrosion problems. [7]

An entire F-80, Shooting Star, jet fighter was made from magnesium and flown in 1955. The thick skin magnesium design that was successful on the monocoque wing design was applied to the fuselage, empennage, ailerons, flaps and other structural components. Fabrication was by East Coast Aeronautics, Inc.

Beech Aircraft changed to magnesium control surfaces on the Bonanza in 1947. Design in magnesium reduced the number of parts by 337, weight by 3 kg (6 lb), man-hours by 10 per aircraft and production tools required by 57.

Helicopters use large amounts of magnesium, and many of the first missiles and rocket developments included magnesium. The Agena, Titan and Atlas long-range intercontinental ballistic missiles used large quantities of magnesium sheet. The thorium based alloy, HM21 and HK31 sheet was used for the magnesium skins of the vehicles. Much of the radar control equipment, antennas, electronic cabinets, plotting boards, etc were made from magnesium sheet.

Pacific Intermountain Express was using magnesium trailers in 1947. They were 1600 kg (3500 lb) lighter than the steel trailers. Freightliner produced magnesium cabs for their truck line. Various types of delivery trucks were made with magnesium cargo compartments. Fruehauf used magnesium extrusions for their trailers.

Magnesium was designed into material handling equipment:
1) Dockboards, 2) hand carts, 3)Shovels, 4)tote bins, 5) typewriters, 6) Dictaphone machines, 7)Aerial cargo delivery systems.

US Developments in Rolling and Extrusion[13]

Dow eventually purchased a plant site at Madison, Illinois to house a new wrought products production facility. Bill Barnes was hired as an engineer at this plant. He was one of the metallurgists that worked to get the processes for rolling and extrusions developed. The world's largest extrusion press (14,000 tons) was leased (and later purchased) from the government. It was a press that was built for the German magnesium industry, but was not completed before the war's end. Extrusion and rolling mill equipment was moved from Midland, Michigan. During the 1950's, Dow produced a large amount of sheet that was used in aircraft and rocket construction. A very large user of magnesium sheet and extrusions was Samsonite luggage made by Shwayder Brothers. The original Samsonite hard luggage had deep drawn magnesium sheet for both sides and the frames were extruded magnesium. A special pebbled coating of plastic was used to protect the magnesium sides. As the quality of plastic improved and price of magnesium went up, Shwayder replaced the magnesium sheet with plastic, but the frames continued to use magnesium sheet.

Dow committed to wrought magnesium in a big way. The Madison plant was 1,125,000 sq ft under roof. It had an 84-inch hot breakdown mill, plus 84-, 68-, 36-, and 18-inch cold finishing mills. There were several extrusion presses ranging from 250 tons up to 14,000 tons. In addition, the company added complete tool and die shops, heat treating, chemical treating, and painting facilities. Rigid quality inspection equipment was added including an ultrasonic immersion-testing unit. There were 8 special furnace sets consisting of 6 large (5,000 lb) crucibles with a continuous, continuous DC caster. The DC casting pits had a flying saw that sawed off a long piece of ingot or slab while the caster kept casting. In the case of billets, the caster was run until the pit was full and then stopped.

Dow helped develop products for the magnesium sheet that it rolled. The Met Lab also helped design alloy compositions to create the right properties for some very technical uses of magnesium. Magnesium sheet was used on many rockets, including the Vanguard, Jupiter, Titan 1, Polaris, Thor-able Star and the Atlas Agena. Dow worked with the Metropolitan Body Company in 1955. This group built Metro-Lite delivery bodies on an International truck chassis. Floor and roof rails were 0.156 in thick magnesium. The dent resistance of magnesium was very good. Pound for pound, magnesium resists denting better than other metals used in construction. Magnesium sheet for lithographic printing has been a mainstay of the magnesium business. It is more easily handled and etched when compared to aluminum.

Despite all of the work Dow did on magnesium, the Madison plant never achieved magnesium product production that was anywhere near the rated capacity. For a time, Dow used some of the warehouse facilities as a Mid West distribution center for primary magnesium from Texas. Eventually Dow started producing more and more aluminum products and eventually sold the plant to Consolidated Aluminum.. Consolidated (Alusuisse) ran the facility for several years and then sold the plant to Spectrulite Consortium, Inc (SCI) whose owner was William A. (Bill) Barnes. Later, SCI bought the magnesium rolled products business from Dow.

SCI continues as the only major rolling magnesium rolling operation in the world. The large furnace capacities are also being used to recycle magnesium scrap. Many new and interesting products are in SCI's research and development operations.

Brooks and Perkins

There was a great amount of sheet being used and a company that got its start in the wartime production of magnesium fabricated parts, Brooks and Perkins, built a magnesium rolling mill in 1952 in the Detroit area. The founder of the company had been a steel man hired by Dow in 1931 to help develop magnesium fabrication methods. Howard Perkins established the Bay City fabrication plant and was in charge until he left Dow in 1935. He worked with Picard and the National Geographic Society in production of the magnesium gondolas prior to leaving. [21]

Perkins started a business using magnesium for parcel delivery vans built on Ford chassis. In 1943, Perkins took Oliver Brooks as a partner and they got a government contract for deep drawn, under slung, magnesium wing gun fairings for Bell's P-63, the King Cobra. Deep drawn magnesium electronic cases and aircraft parts followed this first contract. The company manufactured all of the eight gun turrets used on the B-36 bombers. The company also produced magnesium sheet turrets for the B-47 and B-52. Perkins had purchased a three stand rolling mill from Alcoa. It was installed in Livonia and used to make sheet and fabrications for the Korean War effort. The company decided to expand the rolling mill and build a magnesium casting plant to produce the slabs, etc for the rolling and extrusion operations. Brooks and Perkins went on to become one of the largest and most innovative groups to produce magnesium fabrications and aerial delivery systems.

Much of the work that B & P did was novel and supported by government contracts. As the price of magnesium increased, B & P were forced to convert more and more of their products into aluminum. The demand for cargo container systems for the large jet passenger planes increased dramatically. The price of magnesium made its use prohibitive and most of the systems were developed from aluminum extrusions and sheet.

Brooks and Perkins also perfected the art of metal spinning for magnesium. Using magnesium sheet, the company made structural shapes, including many aircraft parts, by spinning.

Soviet Wrought Products.[23]

The former Soviet Union has been producing and using magnesium for many years. There are no details on the rolling or extrusion of magnesium. However, it has been reported that Stampings from magnesium alloys were used in the Vostok, Soyuz, Mars, Venus and Lunokhods space vehicles. It has also been reported that KUMZ was the leading producer of magnesium alloys and products in the former USSR. The Stupino plant produced large aviation panels from MA14 alloy by stamping. KUMZ developed complex ribbed stamping of rocket wings from alloy MA2. BKMPO has used VILS process to produce thin sheet manufactures and extruded articles from alloys based on the Mg-Y system (alloys VMD-10 and VMD-10-1).

Specialists at the VILS have developed and introduced into commercial production two lightweight alloys based on the Mg-Li system. Alloy MA21 has a density of 1.69g/cm^3 and the alloy M18 has a density of 1.48 g/cm^3. These alloys have been used to reduce the weight of on-board devices in the space industry.

Twin Roll Continuous Strip Casting

Dow worked with Hunter Engineering in early 1980's to develop a strip casting process for magnesium alloy. A proprietary molten magnesium handling system was developed by Dow and coupled with a Hunter strip caster, originally designed for aluminum casting. The liquid magnesium is supplied to a special set of rolls on the caster and the strip casting of magnesium is started.

Magnesium can be cast with a thickness of 0.30-0.25 inches and directly coiled after passing through the caster. This product then only requires two to three passes on the finishing rolling mill to reach the final gauge for market.

Sumitomo, Thyssen Krupp and the Australian Research group, CSIRO are reportedly all interested in working to develop this process.

Summary

This paper was written to show that a substantial wrought product magnesium business was developed at one time. There is increasing interest in research and development of wrought products in today's global magnesium community. Opportunities for magnesium are being developed in the aircraft industry.

There is little magnesium used in commercial or military aircraft today. It is not clear just what has happened to create this situation. Magnesium is still being used in the magnesium transfer cases that are used on jet engines. Magnesium wheels continue to be used on airplanes. Helicopters use large amounts of magnesium, as casting and as extrusions.

Some of the problem with the lack of use is the lack of education as to actual properties of magnesium and the recent technical advances that have vastly improved many of the properties that aircraft designers need in a structural material. The resistance to use is slowly being overcome with the entry of more producing companies into the material stream. As the automotive use continues to grow, there will be a natural escalation in the amount of knowledge available about magnesium.

In aircraft, part of the problem is the life cycle of the aircraft. Many designers are looking at aircraft such as the B-52's and 707's. Many of these aircraft are older than the pilots that now fly them. The designer now has to use materials that will resist corrosion for a much longer period. Magnesium has been suspect because of its remembered corrosion problems from times past. Although many of the corrosion problems have been physically and technically overcome, the information needs to be disseminated and repeated (and repeated) for reinforcement.

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...Me Yesterday, Today, and Tomorrow In this paper, I will be reflecting back on my young life and the situations and decisions that lead me to where I am today. I will be reviewing Uri Bronfenbrennerâ€™s theories and how they relate to me. I will discuss how his ecological theoryâ€™s contexts (Witt & Mossler, 2010, Urie Bronfenbrenner and Ecological Theory, para 2.8) have affected my development into the person I am now. Urie Bronfenbrenner believed that human development formed from the interaction of a person and their environment (Witt & Mossler, 2010, Urie Bronfenbrenner and Ecologica Celebrated in books, movies, musicals and television specials in several countries, Marco Polo is today a hero in Italy and in China: Venice named its airport after a beloved native son. There's the Marco Polo bridge outside Beijing, and no tourist to the Chinese capital in the 1980s was ever allowed to miss the Marco Polo Carpet Shop at the Temple of Heaven. Across Asia, in tributaries of the storied Old Silk Road that linked West and East, Polo's name beckons modern travelers to restaurants, hotels and souvenir shops (Montalbano, 1996, A1). Title: Magnesium Wrought and Fabricated Products â€" Yesterday, Today and Tomorrow. Authors: R.F. Brown. Reference: Kaplan, HI editor (2002) Magnesium Technology 2002, TMS, Warrendale, PA 2002 Magnesium Technology. Affiliation: Magnesium Assistance Group, Inc USA. Magnesium R&D Technology. Home. General. International. Electrolytic Technology.