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HIGH STRENGTH ALUMINIUM-ZINC-MAGNESIUM ALLOY DEVELOPMENT IN GERMANY.

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HIGH STRENGTH ALUMINIUM ZINC-MAGNESIUM ALLOY DEVELOPMENT IN GERMANY

Reported by:

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METALLURGY

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16/7/46 Visit to Professor Hansen, Göttingen.

17/7/46 Visit to Dr. Väth, Essen.

18/7/46 Visit to Professor Bollenrath, Aachen

19/7/46 Visit to Westfalische Metallwerke, Nachrodt.

(Dir Bothmann, Dr. Altwicker, Dr. Mohr, Dr. Vosskühler, Dr. Ing Weber.)

25/7/46 Attempt to see Dr. Siebel, Stuttgart.

HIGH STRENGTH ALUMINIUM-ZINC-MAGNESIUM ALLOY DEVELOPMENT IN GERMANY.

History.

Attempts had been made to use these alloys at various times before the war but stress-corrosion troubles had been experienced. For some years before the war developments had been pursued actively with the object of replacing copper-bearing alloys of the Duralumin type in wrought forms by alloys practically free from copper. The endeavour was to produce an alloy of adequate corrosion and stress-corrosion resistance that would give strength and general properties as good as those of duralumin after ageing at normal temperatures.

Alloys were developed by I.G. Farben on the one hand and by Durenermetallwerke and Vereinigte Leichtmetallwerke on the other hand. The I.G. Alloy depended for its stress corrosion resistance on additions of chromium and vanadium while that sponsored by V.L.W. depended on a special heat-treatment. The Luftministerium regarded the I.G. alloy as the better and instructed V.L.W. and Düren to make this alloy. These two latter firms however used a different method of casting. They were not so successful in attaining specification mechanical properties and special concessions had to be arranged (Dr. Väth).

Production.

According to Dr. Altwicker the total I.G. production of these alloys during the war was 5,000 tons:-

Extrusions	4,000 tons
Forgings	800 "
Sheet	100 "

This was about 10% of the total production.

The quantity of the alloys produced during the war was restricted, according to Dr. Väth (of the Luftministerium), by the shortage of pure aluminium.

Composition.

For aeronautical purposes the aluminium-zinc-magnesium alloy was supplied to specifications Fliegwerkstoff 3415 and Flw 3425. The main requirements of these materials are indicated in Appendices I and II. Prof. Max Haas states that Specification Flw 3415 was never officially issued and his observations on the matter are given in Appendix III.

Discussions with experts of I.G. and of V.L.W. indicated that the compositions preferred by these groups were:-

		Zn.	Mg.	Mn.	Cu.	Cr.	V.
I.G.	Flw 3425	4.5	3.5	0.3	∅	⊁ 0.2	⊁ 0.04
V.L.W.	Flw 3425	4.5	3.5		0.5	0.2	0.03
"	Flw 3415	4.8	3.1	0.7	0.1	Nil	Nil

Casting.

Chlorine treatment of melts was employed in I.G. establishments. V.L.W. stated that they did not use fluxes nor other de-gassing agents on alloys of this class but employed electric furnaces for melting. To secure satisfactorily low gas contents in their production work they allowed the metal to stand in the molten condition during a suitable period. I.G. made cast billets for extrusions and forgings by their "bucket mould" practice. They allowed the alloy to settle for 40 minutes before freezing and claimed to take the temperature down very close to freezing point before lowering the "bucket" into the water. Prof. Bollenrath said that this method sometimes gave very large grain size but it was essential for maximum corrosion resistance because it gave least zinc segregation and he regarded it as superior practice to that of V.L.W. and Durener. Because of licence restrictions, V.L.W. and Durener did not use this method.

I.G. now consider the semi-continuous D.C. casting process as operated at Westfalische Leichtmetallwerke, Nachrodt, is suitable for and effective in production of slabs for direct rolling to sheets.

V.L.W. stated that they had had trouble with billet cracking and with segregation of chromium and vanadium constituents in the manufacture of the I.G. type material. They also stated that copper increased the tendency to crack during or shortly after casting of the billets.

Extrusion.

Durener and I.G. claimed that the alloy (Flw 3425) was as easy to extrude as Duralumin. Extrusion temperatures were 420 to 460°C.

Sheet Rolling.

All sheet was unclad. Cladding with various coatings had been tried. V.L.W. had tried pure zinc and high zinc Al-Zn alloys without success and they regarded pure aluminium as unsuitable because it was cathodic to the alloy.

Prof. Bollenrath said that D.V.L. had reached the conclusion that cladding with an alloy containing 2% of $Mg\text{-}Zn_2$ was best.

The slabs cast at Nachrodt (Westfälische Leichtmetallwerke) with a semicircular edge, and about 4" thick were stated to roll very well without edge cracking. They had rolled sheets in Flw 3425 but none in the more workable alloy Flw 3415. No clad sheets had been made at Nachrodt and they considered cladding unnecessary on sheets made by their technique. Dr. Väth considered that sheets to Specification Flw 3425 were appreciably more difficult to form than duralumin and that appreciable prefiling would have to be done before age-hardening. Sheets to Flw 3415 could, in his view, be formed about as easily as Duralumin.

Dr. Väth and the I.G. experts at Nachrodt thought that alloys to these specifications would be satisfactory in sheet form without cladding for use in civil aircraft in which longer life would be required than in military aircraft, but Prof. Bollenrath was of the opinion that cladding was not only desirable but would be necessary for long life, of the order of 10 years, in aircraft. Dr. Siebel of I.G. appears to hold the same view.

Rivets.

The list of alloys made by V.L.W. (Hanover and Laatzen) given in C.I.O.S. Report on Item 21 File XXXIII-32 includes an item 20/44, Rivetwire, of composition:-

Mn.	Mg.	Zn.	Cu.
0.3-0.6	2.9-3.2	4.2-4.5	0.1-0.3
Si.	Fe.	Cr.	V.
$<$ .5	$<$ .5	0.1-0.2	0.05-0.1

This material appears to be rivet wire to the requirements of Specification Flw 3415.

Mention is made in B.I.O.S. Final Report 279 Item 21 of an alloy.

Mn.	Mg.	Zn.
0.5	2	4

having been made by V.L.W. for rivets but no information could be gained by the present authors on the use of this alloy.

Forging.

Dr. Altwicker, (I.G.), claimed that the forging pressures required were 15% lower than those required for duralumin.

I.G. were very satisfied by the press forging of a taper spar for He 177 from a cast billet 800 mm dia., 2.5 metres long, weighing over two tons. The forging was 9 metres long. Forgings in these alloys had also been used on new types of Ju 188 and Me 109.

Heat Treatment.

I.G. used a cold water quench and wherever possible quenched from extrusion or forging temperatures. In extrusion the section was quenched as it emerged from the die. This was possible because of the wide range of solution treatment temperature permissible with the I.G. alloy which is not true of a copper-bearing alloy. With I.G. precipitation treatment was carried out four days after quenching. I.G. appeared to favour treatment at 100 to 120° C for the final elevated temperature ageing treatment. I.G. and Prof. Bollenrath appeared to agree that ageing at temperatures higher than 150° C gave increased stress-corrosion susceptibility.

The experimental V.L.W. alloy was quenched from 450° into a liquid bath at about 150°, held for a few minutes and then cooled to room temperature. It was subsequently precipitation-treated if required, in the usual manner. It had been previously reported that a precipitation treatment of 4 minutes at 150°-200° was used at V.L.W. but this appears to have been a misunderstanding. The quenching bath was a salt bath, oil, or an aqueous solution of pectin.

Stress Corrosion.

Stress corrosion tendencies were investigated by the standard German methods of immersion in 3% Na Cl with or without addition of hydrogen perioxide, the test pieces being of the 'Schlaufenprobe' (Looptest) or 'Gabel' (fork) types when taken from sheets or sections respectively. Some testing had also been done in pure water at 80°C and in steam. It was admitted that there was no accurate knowledge of stress conditions in these specimens but it was claimed that this did not matter so long as the specimen shape was standardised. Dr. Kostron (V.L.W.) believed that stress corrosion and intercrystalline corrosion in the absence of stress were closely bound up with each other, but that the correlation was not yet complete. Both were probably dependent upon heterogeneity at grain boundaries generally but not necessarily due to the deposition of a second phase.

The amount of laboratory effort expended on stress-corrosion studies of these alloys in Germany indicates very considerable nervousness regarding the practical significance of stress cracking tendency of the alloys.

Exposure Tests.

Exposure tests at tropical stations in Africa and for a short period in Sicily are described in a report by

F. Bollenrath and K. Bungardt of the D.V.L.[1] The only report relating to these tests that the present authors have been able to find is the fourth of a series but appears to be the final one. It may be worth while to indicate here some of the main features of these tests

Samples were exposed for six months (May to October) in 1942 in North Africa at a marine site in Tripoli and an inland site at Castel Benito. The materials included riveted sheets I mm and 2 mm thick manufactured by Durener Metallwerke, I.G. Farben, V.L.W., and Wielandwerke also unriveted sheets from Metallgesellschaft and 0.5 mm sheets from various sources. For comparison sheets from Durener Metallwerke to Flw 3116.5 (1.0 mm), Flw 3126.5 (1.2 mm) and Flw 3126.9 (1.5 mm) were included in the programme.

Flw 3116.5 is of the clad type of fairly low copper dualumin coating of the 1% Mn alloy type, normal temperature aged.

Flw 3126.5 is similar to 3116.5 but of higher copper content in the core alloy (3.8 to 4.5%), and is also normal temperature aged.

Flw 3126.9 is similar to 3126.5 but is aged at elevated temperature, 3 days at 158° ± 3.

The Al-Zn-Mg alloys tested were of four types

	Alloys with 7% Zn + Mg.		Alloys with 8% Zn + Mg.	
	I	II	III	IV
Zn.	4.2-4.8	4.2-4.8	4.2-5.2	4.2-5.2
Mg.	2.4-2.8.	2.4-2.8	3.0-3.6	3.0-3.6
Mn	0.4-0.8.	0.4-0.8	0.2-0.4	0.2-0.4
Cu	0.2-0.3	0.2-0.3	0.2-0.4	0.2-0.4
Si.	0.2-0.4	0.2-0.4	0.2-0.4	0.2-0.4
V.	—	0.05	—	0.05
Cr.	—	0.15	—	0.15
Suppliers:				
	Durener V.L.W.	Metallges V.L.W. Wieland.	V.L.W.	I.G.

(1) "Investigations on the permanence of various Aluminium-Zinc-Magnesium Alloys in the Tropics", F. Bollenrath and K. Bungardt. U & M Report No. 1072 25.9.43 (GDC 10/5680).

Six months exposure in North Africa resulted in an appreciable increase in proof and ultimate tensile stresses of the normal temperature aged Al-Zn-Mg alloys, while the elongation values diminished more or less. The drop in elongation was attributed to corrosion essentially.

The influence of standing outweighed that of corrosion in the I mm and 2 mm sheets but in the 0.5 mm sheets exposed to marine conditions in Tripoli more marked corrosion attack was observed.

Corrosion attack was stronger at Tripoli than at Castel Benito. No indications of intercrystalline attack were detected. Sheets of the clad Al-Cu-Mg alloys were resistant to tropical exposure and showed no significant changes of properties.

The resistance to superficial corrosion of the Al-Zn-Mg alloys of more than I mm thickness was regarded as sufficient on the basis of these tests. Sheets protected by painting, Eloxal treatment or cladding would, on the basis of these tests, and in the opinion of Bollenrath and Bungardt, be just as likely to give no trouble as the clad alloys of the duralumin type (Flw 3115 and 3126). The tests did not indicate significant differences between the alloys of Type I to IV as regards resistance to superficial corrosion. Laboratory tests for stress corrosion tendency by use of the "Schlaufenprobe" (Loop test) used in the D.V.L. "Wechseltauch" apparatus (alternating wet and dry test apparatus - artificial seawater) gave failures in the water quenched and normal temperature aged samples of alloys II and IV only. All other specimens were still sound after 130 days test. No "Schlaufenprobe" (loop) specimens of the water-quenched alloys exposed at Tripoli and Castel Benito failed during six months exposure. No clear connection exists between the results of the laboratory "Wechseltauch" test and the field exposure test results. It is suggested that it may be a matter of significance whether the loop specimens are made from a normal temperature aged sheet and then exposed at raised (tropical) temperature in the bent and stressed condition or whether the sheet is first aged at raised temperature and loop test pieces prepared from it afterwards. In the latter case a greater stress-corrosion tendency is generally observed.

In the rivets in Alloy I which is free from vanadium and chromium, failures at the head occured during the six month's exposure in Tripoli. Cracking was intercrystalline and was attributed to low stress-corrosion resistance. The authors (Bollenrath and Bungardt) state however that Alloy I is not stress-corrosion resistant after solution heat treatment and water quenching and that the tests had been made on material in an unfavourable condition. All the rivets had been solution treated and water quenched in the normal manner and closed with the normal tools as no special instructions had been put forward by the manufacturers. The rivets in Al-Zn-Mg alloy gave shear strengths of more than 19 tons per sq. inch and those in Alloys II and IV which contained chromium and vanadium were resistant to stress corrosion after solution heat treatment and water quenching.

Some supplementary exposure tests were made at Catania (Sicily) commencing 21.4.43. The test period was only 80 days, shorter than was intended owing to Allied action. The following observations relate to these supplementary exposure tests.

The application of a varnish (Flieglack 7122.70) was without apparent influence on the stress-corrosion resistance of quenched or air-cooled and normal temperature aged sheets of Alloy IV. In the exposure test no 'loop' specimen broke.

Heat treatment in salt baths had been found by service experience to be detrimental to the stress-corrosion resistance of material to specification Flw. 3425.5 This material is the material of nominal composition 4.5% Zn, 3.5 Mg. containing chromium and vanadium additions, solution heat-treated aged at normal temperature and straightened. The exposure tests confirmed that heat-treatment in salt baths is detrimental to the stress corrosion resistance but the injury was rather less in specimens quenched in water at 97°C.

'Plated' i.e. clad specimens were resistant to stress-corrosion. Material of similar type but not containing chromium and vanadium was not stress-corrosion resistant after air cooling from solution treatment temperature whether aged at normal or elevated temperature. The copper content of this material was 0.05%. In material of similar type but higher copper content, air-cooled and elevated temperature aged, no fractures occurred during the test period. With stepped cooling and normal temperature ageing complete resistance to stress-corrosion was obtained, but with elevated temperature ageing a slight tendency to stress-corrosion resulted.

Sheets in an alloy containing 5% Zn, 3% Mg, 0.25% Cu approx. showed no fractures of 'loop specimens' in material air cooled and elevated temperature aged after solution heat treatment. The authors (Bollenrath and Bungardt) consider that the period of exposure in the Catania tests was really insufficiently long.

Appendices 4 and 5.

It had been intended to ascertain the views of Dr. Siebel formerly of I.G. Bitterfeld on matters relating to these materials but he could not be located at the time. Replies to a number of questions submitted later to Dr. Siebel are given in Appendix IV.

A list of Hydronalium Alloys of I.G. manufacture is given in Appendix V.

Summary.

1 Wrought aluminium-zinc-magnesium alloys had been under development in Germany and had reached a considerable production during the war.

2. The 4.5% zinc 3.5% magnesium type had been selected as the type preferred. Additions of small amounts of chromium and vanadium had been advocated by I.G. for improvement of stress-corrosion resistance of the alloys. V.L.W. claimed to achieve satisfactory resistance to stress-corrosion in alloys not containing additions of chromium and vanadium by special heat-treatments.

3. The alloys were studied initially as a possible means of providing material having properties as good as those of duralumin but free from copper which was in short supply.

4. The high strength properties of the elevated temperature aged alloys and the improvement in stress-corrosion resistance by elevated temperature ageing came to be recognised as development of the alloys proceeded. There appears however to have been a good deal of apprehension regarding stress-corrosion tendency.

5. The alloys had been used to a moderate extent in the form of highly stressed forgings, sections and un-clad sheets for aircraft made in the later part of the war.

APPENDIX I

The main requirements of Specification Flw 3415 (March 1942 issue)

Zn	Mg	Mn	Cu	Si	Fe
4–5%	2–3%	0.4–1%	0.1–0.3%	< 0.7%	< 0.5%

	.2% Proof T/in²	UTS T/in²	El%
Sheets up to 6 mm thickness. Normal temperature aged. Strips up to 3 mm thickness. Normal temperature aged.	15.9	25.4	15
Sheets up to 6 mm thickness. Normal temperature aged and straightened. Strips up to 3 mm thickness. Normal temperature aged and straightened.	17.8	26.7	13
Sheets up to 6 mm thickness. Elevated temperature aged. Strips up to 3 mm thickness. Elevated temperature aged.	22.9	29.2	8
Extruded sections 1.5–15 mm wall thickness. Normal temperature aged and straightened.	17.8	25.4	10
Extruded sections. Elevated temperature aged.	21.6	27.9	8
(Transverse		21.0	2) ø
Wires and rods up to 2000 mm² Normal temperature aged and straightened.	17.8	26.7	10
Extruded bars 2000–5000 mm², normal temperature aged.	15.9	25.4	10
(Transverse	14.0	19.0	3) ø
Bars 5000–8000 mm², extruded or forged, normal temperature aged.	15.2	24.1	10
(Transverse	14.0	19.0	3) ø
Bars 8000–11300 mm², extruded or forged, normal temperature aged.	14.6	22.9	8
(Transverse	14.0	19.0	3) ø
Bars 11300–20000 mm², forged, normal temperature aged.	14.0	22.9	8 ø
(Transverse	14.0	19.0	3) ø

ø Elongation on 5 mm.

Solution treatment temperature 440–460°C

Normal temperature ageing at least 30 days at 20°C or 4 days at 50–60°C.

Elevated temperature ageing 2 to 4 days at 120–90°C.

.2% Proof stress/ult. stress ratio should be less than 85%.

APPENDIX 2.

The Main Requirements of Specification Flw 3425

Zn	Mg	Mn	Cu	Si	Fe	Cr	V	Ti
4.3 to 4.8	3.3 to 3.8	0.1 to 0.5	0.2 to 0.6	>0.4	>0.5	0.1 to 0.2	0.02 to 0.06	> .1

	.2% Proof T/in²	UTS T/in²	El%
Extruded sections 1.5-6mm thick. Normal temperature aged.	16.5	25.4	12
Extruded sections 1.5-6mm thick. Normal temperature aged and straightened.	17.8	25.4	12
Extruded sections over 6 mm thick. Normal temperature aged.	17.8	26.7	10
Extruded sections over 6 mm thick. Normal temperature aged and straightened.	19.0	26.7	10
Drawn bars up to 2000 mm². Normal temperature aged and straightened.	17.8	26.7	10
Extruded bars 2000-5000 mm². Normal temperature aged.	17.8	26.7	10
Extruded, forged bars 5000-8000 mm². Normal temperature aged.	16.5	25.4	10
Extruded, forged bars 8000-11,300 mm². Normal temperature aged.	15.9	24.1	8
Forged propellers (root). Normal temperature aged.	17.8(L)	26.7(L) 21.6(T)	10(L) 6(T)
Forged bars 11300-20000. Normal temperature aged.	15.2	24.2	8
Extruded sections 1.5 to 3 mm thick. Elevated temperature aged and straightened.	25.4+	30.5	8

(L) - Longitudinal. (T) - Transverse. + $\frac{\text{.2\% Proof Stress}}{\text{U.T.S.}}$ ≯ 90%

	.2% Proof T/in^2	UTS T/in^2	El%
Extruded sections 3 to 6 mm thick. Elevated temperature aged and straightened.	25.4+	31.75	8
Extruded sections over 6 mm thick. Elevated temperature aged and straightened.	26.7+	31.75	8
Forged propellers (root). Elevated temperature aged	26.7(L) 21.6(T)	31.75(L) 25.4 (T)	8(L) 4(T)
Press forging, Elevated temperature aged.	26.7(L) 21.6(T)	31.75(L) 26.7 (T)	8(L) 4(T)
Open forgings.	As required.		
Drawn or extruded, or forged bars up to 8000 mm^2. Elevated temperature aged.	26.7(L)+ 22.9(T)	31.75(L) 26.7(T)	8(L) 4(T)
Extruded or forged bars over 8000 mm^2 up to 11300 mm^2. Elevated temperature aged.	26.7(L)+ 21.6(T)	31.75(L) 25.4(T)	8(L) 4(T)
Forged bars 11300–20000 mm^2. Elevated temperature aged.	25.6(L)+ 20.3(T)	30.5(L) 24.1(T)	8(L) 4(T)

(L) - Longitudinal. (T) - Transverse. + $\frac{\text{.2\% Proof Stress}}{\text{U.T.S.}}$ 90%

APPENDIX 3

Fliegwerkstoff 3415.

(Note by Professor Max Hass, October 1946)

The constantly increasing scarcity of copper in Germany made it imperative to develop a "Fliegwerkstoff" which consisted of the materials that were available on the home market i.e. aluminium, zinc and magnesium. The RLM (Ministry of Airways) took up again the old alloying type Constructal which had been brought on the market 20 years ago by Messrs. Goldschmidt, Essen. This alloying type was very sensitive towards stress corrosion and had, therefore, not been further developed. The age hardening component was $Mg\ Zn_2$. In the meantime the influence of the proper heat treatment resp. of the stabilizers chromium, vanadium, titan and manganese and their intercrystalline and surface gliding preventing properties of the crystals as a counter action against stress corrosion had been explored, and practical tests had been made with success.

Since number of years the demand for a super-duralumin had been raised and famous American, English, German, French and Japanese explorers have been busy with this problem on the base of the Al-Zn-Mg-alloys. In Germany the I.G. Farbenindustrie worked chiefly with the stabilizers chromium and vanadium in the presence of copper, whereas the Vereinigte Leichtmetallwerke propagated the addition of manganese and a proper heat treatment, which latter one was also recommended by the Dürener Metallwerke. Before the end of the war the RLM had just started a large scale testing program by combined efforts and for this purpose the "Fliegwerkestoff"-Form 3415 had been drafted.

Description: Only about 100 forms of the "Fliegwerkstoff" Form 3415 have been printed and it never has been officially issued. This gives also an explanation to the fact that this form is missing in the "Fliegwerkstoff-Handbuch" which had been edited by the Technical Office of the RLM and the last al-alloying page of which was 3360. It ran thus:

Fliegwerkstoff-Leistungsblatt
Group: Aluminium Alloy 3415
Type: Al-Zn-Mg.
Chemical composition: in%.

Mg 2 – 2.8%
Zn 4.5–5.5%
Si 0.7%
Mn 0.2–0.3% according to RIM prescription x)
Cu 0.5%
V 0.08%
Cr 0.2%
Fe up to 0.5%

VLW Hannover used 0.6–1% Mn. The RIM was of opinion that primary FE Al_3 segregations would take place which might give cause for troubles.

Material-Index.
Shape: shaping sheets.

Proof Stress δ F (0.2)		25 kgmm^2
Tensile Strength: δ B		38 kgmm^2
Elongation on Break: δ 10		12%
Treatment:	Cold age hardening.	

Criticism:

The Fliegwerkstoff 3415 Al-Zn-Mg was equivalent to the Fliegwerkstoff 3116 Al-Cu-Mg plated, but efforts were being made to realise a super-duraluminium quality with Fliegwerkstoff 3425, having the index numbers 42/50/8. The aim was to realise 42/55/6.

According to German opinion the English alloy Hanco containing 7–8% of zinc and 2 Mg with chromium as stabilizer contains too much zinc and magnesium. The same applies to the American alloy 75 S with 7.5% Zn, 1.5% Mg, 0.5% Mn and 0.5% Cu.

It was an impossibility to introduce the Al-Zn-Mg alloy during the war in Germany because of the scarcity of raw materials (too high virgin aluminium stock required and two sorts of scrap).

In times of peace and under international aspects, the introduction and use of this kind of super-duraluminium will be of interest and successful. Scrap refining would be given a fair chance and good prospects with this new process. To eliminate any set-back, large scale trials must be made. For the purpose to avoid any mix-up of scraps and to clear the scrap situation once and for all, it would be necessary to exclusively use zinc-alumin instead of the copper-duralumin used up till now.

I have found out later on that three of the largest plants have made a large scale trial in 1943 for forging purposes and have used 120-150 tons with success. The analysis of the Fliegwerkstoff 3415, June 42 (analysis for propellers) was a compromise which met the demands of all manufacturers. The discrepancies of the analysis compared with the figures given in this report may be explained thereby. The superiority of the Al-Zn-Mg alloys compared to Duralumin was the better hot forming property and the better values by forging the pressed parts, furthermore the subsequent ageing when being stocked. Regardless whether cold or hot age hardening took place the alloys become more compact or more brittle and show bad workability figures especially for sheets.

Prof. Dr. Ing. Haas.

APPENDIX 4.

Questions submitted to Dr. Siebel (I.G.) and replies.

At the time of the author's visit Dr. Siebel was away from home. By courtesy of F.I.A.T., Frankfurt the following questions were submitted to Dr. Siebel and he supplied the answers given below.

1. What scientific investigations led to the composition selected by I.G. Research staff as the best one for this type of material?

Dr. Siebel - Systematic investigations of the ternary Al-Zn-Mg system showed that alloys on the Section Al-Hy 43 possessed good stress-corrosion resistance and good elongation values. Alloys on the Al-Al_2Mg_3-Zn_3 and Al-Mg-Zn_2 sections were stress-corrosion sensitive (see list of publications).

2. Can Dr. Siebel give titles and numbers of reports dealing with exploratory work of I.G. Research Laboratory or other laboratories on these alloys?

Dr. Siebel - List of reports is appended.

3. Did I.G. investigate the constitution of the alloys containing small amounts of Cr and V and did they reach any conclusion as to the mechanism by which these additions gave improvement of the stress-corrosion resistance? References to relevant reports should be given if possible please.

Dr. Siebel - The solubility of Cr, V, Ti and other stabilisers in Hy 43 was determined. Further, the influence of these stabilisers on the mechanical properties and stress-corrosion properties was determined on both extruded and rolled material very thoroughly. The results are given in the reports.

4. What are the general impressions of the I.G. Research Team on the reliability of the alloys and their suitability for use as engineering materials where a long life, e.g. 10-15 years is required?

Dr. Siebel - Extruded material, Hy 43 fully heat-treated can be used without question in practical applications for long periods of 10-15 years. It should be superior to the Duralumin hitherto used, especially the elevated temperature aged Duralumin.

For sheets Hy 43 in the normal temperature-aged condition only, the workability and stress-corrosion resistance are somewhat inferior to those of Duralumin. Other Al-Zn-Mg sheet alloys have been developed which, when plated are apparently as good as Duralumin. In this field there have been extensive investigations which have not yet been published.

5. Does Dr. Siebel consider that uncoated sheets in Hy 43 would be satisfactorily resistant to stress-corrosion during periods of 10-15 years in civil aircraft?

Dr. Siebel - Hy 43 unplated is inferior to Duralumin and especially to Duralplatt (vide 4).

6. Does Dr. Siebel consider that profiling operations on sheet and strip and slight bending or straightening of extruded sections should be carried out in the annealed or solution-treated condition rather than after the completion of heat-treatment operations?

Dr. Siebel - All forming operations should in principle be carried out on homogenised Hy 43 wrought material only. In the fully heat-treated condition the material is capable of withstanding quite considerable deformation of an extrusion ratio under 90%, but from the point of view of stress-corrosion, working of material in this condition should be avoided wherever possible.

7. Does Dr. Siebel consider that all the stress-corrosion tests they made in the laboratory gave them the best alloy for freedon from stress-corrosion troubles in service or that the tests gave exaggerated differences in stress-corrosion behaviour which would not be of significance in service? How were results of laboratory tests correlated with service performance of the alloys?

Dr. Siebel - In the laboratory tests (Gabel (fork) tests, Schlaufen (loop) tests, etc) rapid methods are concerned and these serve the purposes of -

1. evolving alloys having improved stress-corrosion resistance,
2. clarifying the whole problem of stress-corrosion
3. distinguishing susceptible material from that which is resistant to stress-corrosion in works control.

In comparison with stress-corrosion conditions in service, the laboratory test methods are naturally much too severe, and there is today still no relationship between behaviour under the rapid tests and behaviour in service. However, there can be no doubt that for further development of high strength light alloys, stress corrosion testing in the laboratories is necessary, and that the present test methods in spite of their disadvantages, do give a significant indication of the stress-corrosion behaviour of a material, and of the way it will behave in service. With the help of these methods, the stress-corrosion resistant Al-Mg, and Al-Zn-Mg alloys were developed by I.G.

8. Does Dr. Siebel regard Al-Mg alloys containing more than 5% of magnesium as being capable of being free from stress-corrosion troubles if they are either

(a) correctly heterogenised,
(b) contain approx. 1% of zinc.

Dr. Siebel - according to the improved heterogenisation treatments evolved by ourselves, the binary Al-Mg sheet alloys e.g. with 8.5% Mg, 0.3% Mn. are practically resistant to stress-corrosion even after reheating to 100°C. (Aluminium 1942 pp 129-130).

The Al-Zn-Mg alloy Hy 18 (8% Mg, 1% Zn, 0.3% Mn and 0.12% Cr) is, in the homogeneous condition, appreciably more stress-corrosion resistant than the homogeneous binary Hy 9 alloy, but not so stress-corrosion resistant as Hy 9 sheet produced by the latest heterogenising process. The general corrosion resistance of Hy 18 sheets is also somewhat inferior to that of Hy 9 sheet (Vide Zeits für Metallk, Vol. 32, 1940, pp 298-302 and Jahrbuch 1938 der deutschen Luft fahrt forschung).

9. Were I.G. completely satisfied that Hy 18 could be used satisfactorily in conditions of heat-treatment and cold work other than that in which the sheet or strip was supplied by I.G.?

Dr. Siebel - Experience in practice has not yet shown whether Hy 9 or Hy 18 has the greater advantages. Since the beginning of the war, these alloys have not been in production. No large quantity of Hy 9 sheets has yet been made by the latest heterogenising process, so that a satisfactory comparison between the new Hy 9 and Hy 18 is not yet possible. On the grounds of laboratory test results, the heterogeneous Hy 9 should give better performance than Hy 18 sheets.

10. Did I.G. do any electron-microscope work on light alloys, particularly on precipitation hardening?

Dr. Siebel - Investigations with the electron microscope on light metals have not up to the present been made by us owing to pressure of more important problems but were planned.

11. References to the more important I.G. reports on these alloys (Hydronalium Alloys - including Hy 43) should be given please.

Dr. Siebel - List of papers attached.

12. What were the results of I.G. investigations of the fatigue properties and notch sensitivity of Hy 43 in wrought forms - forged and also extruded? Are there any I.G. reports?

Dr. Siebel - Extensive investigations on the bending fatigue strength of Hy 43 extruded, forged, and rolled have been made. One can summarise by saying that the fatigue strength of Hy 43 is practically equal to that of Duralumin. By elevated temperature ageing of Hy 43 the strength properties (Proof Stress, Ultimate Tensile Stress) are raised appreciably but the fatigue properties are not improved appreciably.

I.G. Publications on Al-Zn-Mg Alloys.

1. G. Siebel and H. Vosskühler. "Influence of additions, especially of Zinc, on the corrosion behaviour of Al-Mg alloys" Z. für Metallic 32 (1940) 298-302.

2. G. Siebel and H. Vosskühler. "Strength properties of cold hardened (normal temperature aged) Al-Zn-Mg alloys of 9% Mg + Zn". Metallwirts 19 (1940) pp 1167-1170. Jahrbuch der Deut. Luftfahrtf 1, 1940, p 1062-1066.

3. H. Vosskühler. "Development of a stress-corrosion resistant, cold and warm age-hardening Al-Zn-Mg alloy with high strength properties". Jahrbuch der Deut. Luftfahrtf 1, 1940, pp 1044-1056.

4. H.G. Petri, G. Siebel and H. Vosskühler. "Strength properties of an Al-Zn-Mg alloy with 3.5% Mg and 4.5% Zn cold aged". Aluminium Z4 (1942) pp 385-389.

5. H.G. Petri, G. Siebel and H. Vosskühler. "Strength properties of an Al-Zn-Mg Alloy with 3.5% Mg, 4.5% Zinc". Lilienthal Report A.165. Jahrbuch der Deut. Luftfahrtf. I, 1942, pp 744-753.

6. W. Rosenkranz. "Preparation and working of the alloy Hy 43/DVL and strength properties of extruded and forged products". Lilienthal report A.165. Jahrbuch der Deut. Luftfahrtf. I 1942 pp 766/72.

7. H.G. Petri, G. Siebel and H. Vosskühler. "Influence of additions on the stress-corrosion behaviour of an Al-Zn-Mg Alloy with 4.5% Zn, 3.5% Mg". Aluminium 26 (1944) pp 2-10.

8. G. Siebel, "Determination of solubility of $Mg.Zn_2$ in Aluminium". Z. für Elektrochemie 49 (1943) S.218/28.

9. H. Vosskühler. "Constitutional investigation of an Al-Zn-Mg alloy with 4.5% and 3.5% Mg. (Hy.43). Z. für Metallic 36 (1944) pp 195-197.

10. H.G. Petri and G. Siebel. "Comparative stress-corrosion tests or Al-Cu-Mg and Al-Zn-Mg Alloys". Aluminium Z6 (1944) pp 190 & ff.

APPENDIX 5.

Hydronalium Alloys.

The following schedule was kindly supplied by Colonel W.T. Vigers and Mr. H.G. Ridge of Metallurgy Branch, Trade and Industry Division, 64 HQ, CCG(BE), Minden, B.A.O.R.

WROUGHT ALLOYS.

F.L.W. Number	Designation	Mg%	Zn%	Mn%	Si%	Cr%	Remarks
				Composition %			
	Hy25	2	--	0.2-0.6	0.5	--	Thin wire (for filters) Rivets: good spinning, welding and polishing properties.
	Hy25	2	--	--	0.5	--	As above. Good anodising properties.
	Hy 3	3	--	0.2-0.6	--	--	Deep drawing and spinning
3305	Hy 5	5	--	0.2-0.6	--	--	Deep drawing A high strength alloy exhibiting considerable work hardening.
3310	Hy 7	7	--	0.2-0.6	--	--	Sea-water resistant.
3315	Hy 9	9	--	0.2-0.6	--	--	Never came into production. Only small amounts made.
	Hy18	8	1	0.2-0.6	--	--	Better stress corrosion properties than Hy9. Experimental alloy only.

WROUGHT ALLOYS (Continued)

F.L.W. Number	Designation	Mg%	Zn%	Mn%	Si%	Cr%	Remarks
3425	Hy43	3-3.5	4-4.5	0.2-0.6	--	.15-.25	Forgings and high tensile sheets. (Cr. added as Stabiliser).
	Hy46	4	6	0.2-0.6	--	--	Experimental alloy: did not come into use.

CASTING ALLOYS.

	Hy51	5	--	--	--	--	Gravity die and sand castings: sea water resistant.
	Hy71	7	--	--	1	--	Sand castings: abandoned owing to hot-shortness and poor casting properties.

37-238.G.A.L.Ltd.6-48.