A HYBRID APPROACH TO MANUFACTURING WAVEGUIDE COMPONENTS UTILIZING 3D PRINTED WAX IMPRESSIONS AND NON-FERROUS METAL CASTING

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Abstract -An alternative approach to manufacturing waveguide components and assemblies using 3d printing a wax impression and then investment casting is presented.

Waveguide components are conventionally fabricated using drawn tube, machined components, and castings. These are assembled using brazing, adhesives, or screws. Recently, interest has grown in additive manufacturing of waveguide components, particularly 3d metal printing. An alternative hybrid approach is to 3d print a wax impression which can then be investment cast to produce a metal component. This has several advantages over metal printed components, namely lower surface roughness, wider range of non-ferrous metal alloys (including aerospace grade aluminum, brazeable aluminum and copper alloys), lower printer costs. The possibility of using this technique for manufacturing waveguide components and assemblies has been investigated.

Comparative results are presented for a machined and brazed waveguide bend assembly, a 3d metal printed waveguide bend assembly and a 3d printed wax and investment cast waveguide bend assembly. Additional results are presented for a magic tee, waveguide mixer and monopulse comparator manufactured by 3d printing a wax impression and then investment cast.

I. INTRODUCTION

Additive manufacturing/3d printing has become an accepted technique throughout industry with plastic, ceramic and metallic parts now being manufactured using this technique. 3d printed parts have started to be used in microwave devices, for instance 3d printing of plastics has been used in dielectric lens. Extensive research has been undertaken in the 3d printing of devices such as filters and even waveguide components. This research used either 3d printed plastics with a post process plating of copper or silver or 3d metal printing. The inability to braze these components and thus create larger waveguide assemblies is problematic.

3d printing of metallic parts requires the alloys to be suitable for the process [1] and results in a surface roughness that is dependent on the powder particle size used. Consequently, the alloys used may not meet the mechanical and environmental requirements placed on existing components manufactured by traditional machining and fabrication techniques. In addition, for waveguide components the surface roughness results in a degradation in insertion loss and the high silicon content in the printable aluminium alloys, such as AlSi10Mg (typically 9 to 11%) mean that these components cannot be brazed to produce more complex waveguide assemblies. The brazeable LM31 aluminium alloy has 0.25% silicon content.

Waveguide components have been manufactured since the 1960’s by means of investment castings in both aluminium and copper alloys. This is typically done by making a wax impression (using a complicated die) and then producing a mould from the wax. Finally, the cast waveguide component is made from this mould.

Here we report on a hybrid process where the wax is 3d printed and a cast waveguide component is then made from this wax. Consequently, aerospace grade brazeable alloys can be used with this hybrid approach. Additionally, the surface finish from the hybrid approach is similar to the best currently available 3d direct printed metal parts. The comparative published data on 3d metal printed processes, wax printing and investment casting are shown below (Table 1).

TABLE I SURFACE ROUGHNESS FOR 3D METAL PRINITNG, 3D WAX PRINTING AND INVESTMENT CASTING

3d metal printing processes	**Surface finish /µm**
Wire DED	45 – 200 [2]
Joule printing	30 – 50 [2]
Powder DED	15 – 60 [2]
EPBF	10 – 30 [2]
LPBF	5 – 18 [2]
Binder jetting	3 – 13 [2]
Wax printing process	5 -10 (our estimate)
Investment casting process	≤0.8 [3]

Further improvements on the surface finishes are possible by using additional post processing steps.

II. HYBRID WAX/INVESTMENT CASTING TECHNIQUE AND A WG16/WR90 BEND

The electrical effect of 3d printing waveguide was investigated by manufacturing a WG16/WR90 waveguide bend assembly as a fabricated assembly, a 3d printed metal component and a 3d printed wax that was then cast. All the components were manufactured in the aluminium alloys appropriate to that process. The electrical designs were identical.

The fabricated bend assembly was manufactured from drawn waveguide tube and an investment cast bend (wax made by the die). These were flame brazed together (Fig 1).

A 3d printed waveguide bend was manufactured using direct metal laser sintering (fig 1).

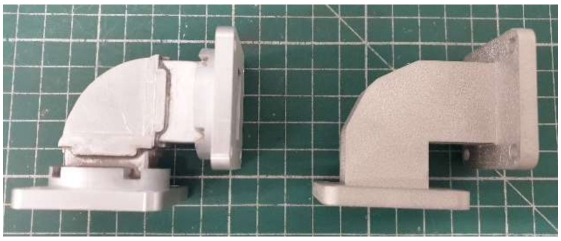

Fig 1 WG16/WR90 Bend assembly. Fabricated and brazed assembly on the left, 3d metal printed on the right.

A Projet MCP2500IC 3d wax printer was used to print a bend in wax (Fig 2).

Fig 2 WG16/WR90 Bend printed in wax

These waxes were then assembled onto a “tree” (Fig 3) suitable for use in a lost wax investment casting process using the block moulding process.

Fig 3 Various 3d printed waxes assembled on the “tree” ready for investment casting

The tree was placed in an investment box and the box filled with a plaster based refactory material. The wax was melted out of the box leaving a mould of the tree (including an impression of the 3d printed wax bend). The tree was then cast in A356 aluminium alloy (Fig 4).

Fig 4 Castings of the 3d printed waxes on the tree

The investment cast waveguide components are then cut off the tree and a waveguide bend manufactured from a wax impression is shown below (Fig 5)

Fig 5 Cast bend manufactured from a 3d printed wax

The return and insertion loss were measured across the full operating band of WG16/WR90 waveguide (8.2 to 12.4 GHz). Additionally, the surface roughness was measured for each part. These measurements are shown in Table II.

TABLE II AVERAGE INSERTION LOSS OF THE BENDS

Process	**Average insertion loss dB**	**Return loss dB**	**Surface roughness Ra µm**
Brazed and fabricated bend	-0.03	≤-28	1.5
Direct metal laser sintering	-0.14 (-0.03 after flanges lapped)	≤-30	15.6
Wax printing & cast	-0.03	≤-34	4.5

The investment casting process has a post processing step, which is to lap the flanges, therefore an additional measurement was taken for the direct metal laser sintered part where the flanges had been post process machined. This improved the average insertion loss, for the direct metal laser sintering, to -0.03 dB. Thus, showing that the increased insertion loss of a direct printed waveguide components, is mainly associated with the" as printed" surface roughness of the flanges.

III. MAGIC TEE

Using the hybrid approach of investment casting a 3d wax printed impression a magic tee was manufactured (fig 6). This magic tee had previously been manufactured as a machined and dip brazed assembly.

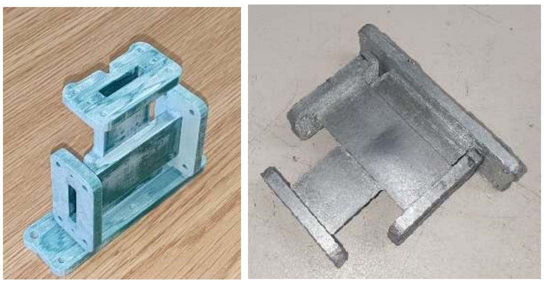

Fig 6 3d printed wax impression of the magic tee & investment casting of the magic tee

The magic tee met the electrical specification

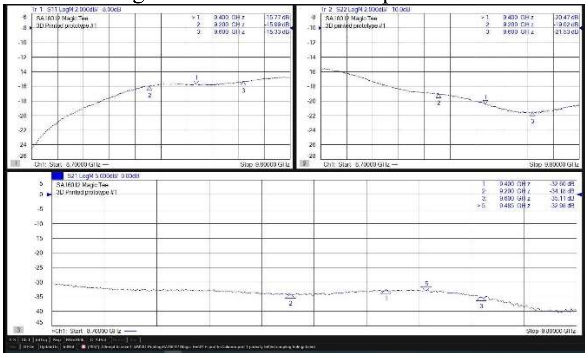

Fig 7 Test Results for the wax printed/investment cast magic tee (Top Left – E port return loss, Top Right H- Port return loss, Bottom – E/H port isolation)

The fabricated and brazed component consisted of 8 cnc machined components, demonstrating the advantages of the wax printed/investment cast process in parts and lead time reduction.

IV. MIXER

A waveguide (WG16/WR90) mixer was also manufactured using this hybrid approach (fig 8) and the test results are below (fig 9). These meet the required specification.

Fig 8 Waveguide mixer manufactured from a 3d printed was impression and investment cast

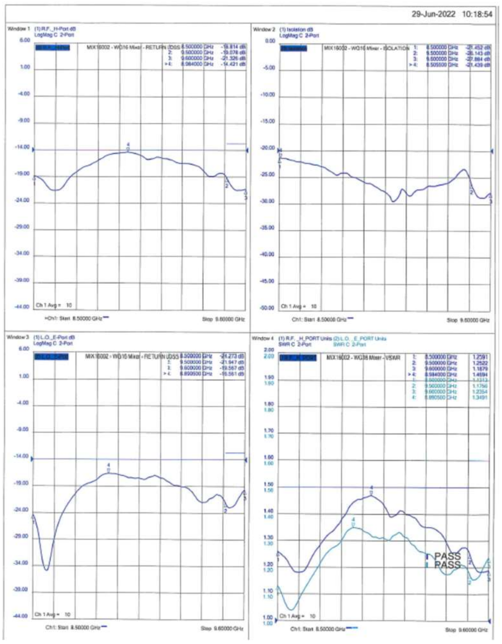

Fig 9 Test results of a waveguide mixer made by 3d printing a wax impression and investment casting (Top left – Return loss port 1, Top right – Isolation, Bottom left – Return loss port 2, Bottom right – vswr port 1& 2)

The machined and fabricated version of this mixer has been in serial production for several years and consists of 2 cnc machined parts dip brazed together.

V. MONOPULSE COMPARATOR

A monopulse comparator is a much more complicated waveguide device, consisting of 4 magic tees (or hybrids) arranged in such a manner that when used with an antenna split into 4 quadrants; signals proportional to the sum of the returned signal of the antenna quadrants, the difference of the returned signals in azimuth and the difference in elevation are obtained. These three signals can then be used, with suitable processing, in a monopulse radar system [4].

An existing design operating from 15.5 to 17.0 GHz was used to prove whether a monopulse comparator could be successfully manufactured using a 3d printed wax impression which is then investment cast. The existing design is manufactured from 13 components which are either machined, cast, or extruded and then brazed together. The 3d printed wax/investment version consists of four components (fig 10).

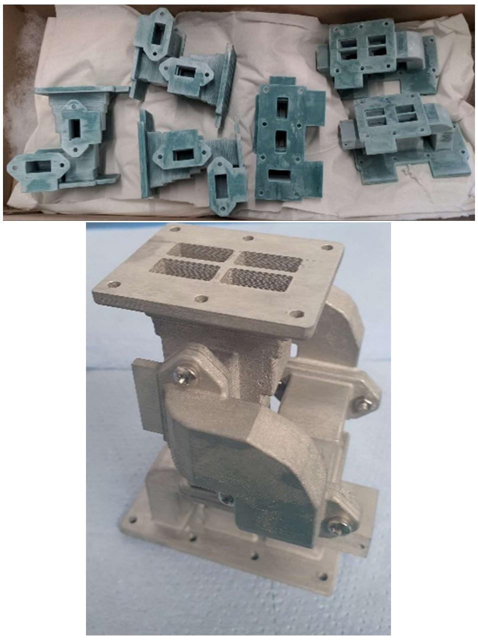

Fig 10 Monopulse comparator manufactured from 3d printed waxes and the investment cast (Top -waxes, Bottom – cast and assembled)

The electrical test results of the assembled comparator are shown below (fig 11a & b).

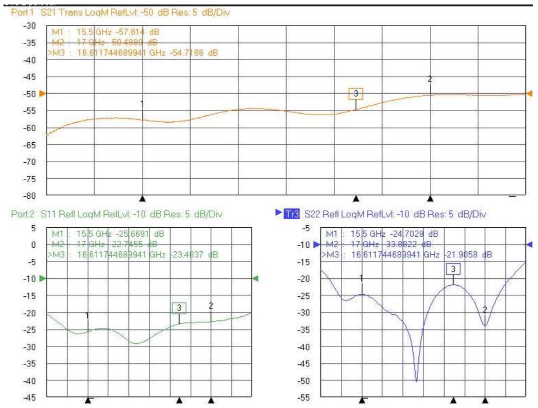

Fig 11a Electrical test results for monopulse comparator (Top - Sum/E difference channel isolation, Bottom left – Sum channel return loss, Bottom left -E difference channel return loss)

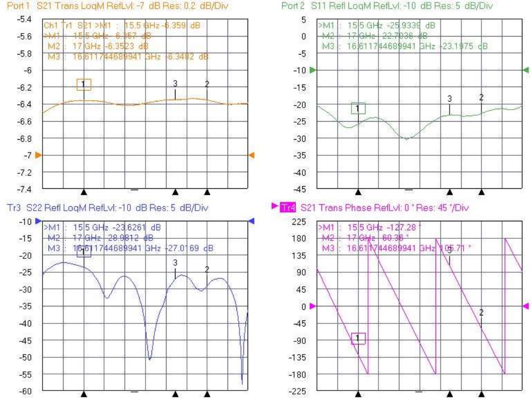

Fig 11b Electrical test results for monopulse comparator (Top left -Sum to Quadrant A port power division, Top right – Sum return loss, Bottom left – Quadrant A return loss, Bottom right – Sum to Quadrant A phase)

The monopulse comparator manufactured by assembling castings made from investment casting 3d printed wax impressions had very similar performance to the machined and fabricated version.

VI. CONCLUSIONS

It has been demonstrated that 3d printing a wax impression of a waveguide component and then investment casting it results in waveguide devices with similar performance to machined and brazed waveguide components. Additionally, it has been demonstrated that a 3d metal printed component has higher insertion loss than a machined and brazed component, however this is mainly associated with the surface roughness of the flanges and post processing the flanges results in similar losses to a machined and fabricated waveguide assembly.

The 3d printed wax/investment cast components are manufactured in brazeable aluminium alloys therefore they can be brazed into larger assembles and waveguide runs unlike direct printed metal parts which use AlSi10Mg which cannot be brazed.

VII. FURTHER WORK

It is intended to demonstrate that the waveguide components manufactured from a printed 3d wax impression and investment cast can be

1) Flame brazed together
2) Dip brazed together
3) Waxes can be assembled together,
4) allowing larger assemblies to be built with a significant reduction in the number of flanges.

[1] T. Mukherjee, J. S. Zuback, A. De and T. DebRoy, “Printability of alloys for additive manufacturing,” *Scientific Reports,* 2016.

[2] A. Huckstepp, “Surface Roughness – A Guide to Metal Additive Manufacturing by Digital Alloys,” 19 September 2019. [Online]. Available: https://manufactur3dmag.com/surface-roughness-a-guide-to-metal-additive-manufacturing-by-digital-alloys/. [Accessed 25 August 2022].

[3] Sylatech Ltd, “Sylatech's engineering design guide,” [Online]. Available: https://sylatech.com/sylatechs-engineering-design-guide/. [Accessed 25 August 2022].

[4] S. M. Sherman, Monopulse principles and techniques, Artech House, 1984.