Technologies and practical experiences on AC end of life operations from a dismantler's point of view

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Introduction

Aircraft are the most secure operating vehicles for public transport. The awareness of the tragic and fatal consequences of an accident made the aircraft industry devote a great deal of attention to ensure the safety of its vehicles. Part of this safety comes from the use of highly developed and much specialised materials. With focus on safety, reliability and economic and environmental friendly operations, the recyclability is of secondary importance. The focus of the aircraft industry is to manufacture aircraft with less fuel consumption, ones that are lighter, faster, safer and quieter. This implies also the usage of newly developed materials for aircraft manufacturing. The recycling industry has attuned itself to the recycling of the present materials and the future high-tech laminated materials.

Universities support the recycling-industry with the challenge of handling those new materials. By researching new treatment possibilities for materials from end-of-life-aircraft approaches to close the material-loop are being made. This article provides an overview over the interaction from preparatory actions including the pre-crushing to the recycling-process for creating secondary raw materials. It will give an inside in how the existing recycling-process for end-of-life-vehicles could be a vantage point for aircraft recycling.

Figure 1 shows possible material loops in the life of an aircraft. The picture proposes a recycling route on the basis of reuse, material recycling, feedstock recycling or energetic recovery. The average lifespan of an aircraft with 20 to 30 years is significantly longer than those of other industrial goods respectively vehicles, for instance cars. Post-production-recycling is not considered in this figure. The focus is on end-of-life-aircraft.

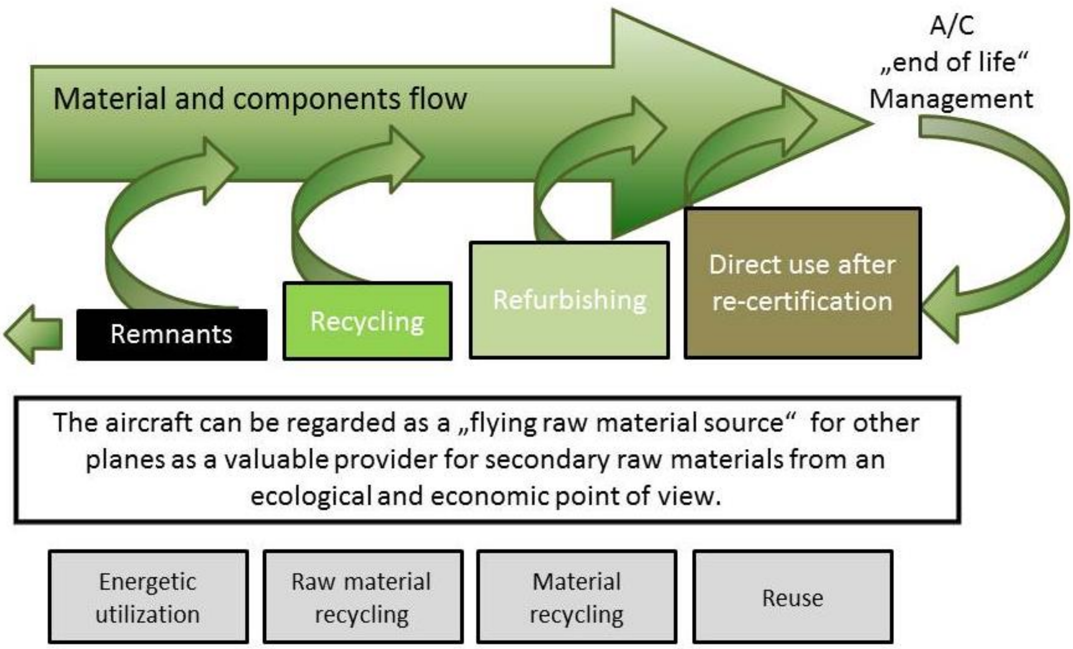

Figure 1: Possible recycling routes [own research]

From an economics' point of view an important first step to the realization of a “closed-loop-process” is the building of cooperation between aircraft spare-part dealers and professional dismantling companies. By that an end-of-life management service for old aircraft can be established. That means that the entire unit “end-of-life-aircraft” can be handled. For example the dismantling and disposal costs have to be included in the high part components calculation. It is worth to take a closer look at the product liability of the aircraft manufacturers. In Europe, the dismantling and disposal costs exceed yet the residual value of an old aircraft. This would of course change if many aircraft could be accumulated at one dismantling area. But this is not always easy to realize because ferry flights are very expensive and sometimes some authorities might prohibit certain aircraft from flying as can be seen in the list of air carriers which are subject to an operating ban from the European commission [1]. Therefore the airworthiness of an aircraft also needs to be taken into consideration.

To develop a new approach to international aircraft recycling, a German consortium was formed. Funded by the German Federal Ministry for Education and Research (BMBF) the joint project “MORE-AERO” targets a mobile approach to pollutant removal, dismantling and recycling of end-of-life aircraft. This is a unique development. The project team consists of Süderelbe AG, STUTE Logistics (AG & Co.) KG, TU Clausthal Institute of Mineral and Waste Processing, Waste Disposal and Geomechanics (IFAD) and the Keske Entsorgung GmbH. The recycling company Keske Entsorgung GmbH acts as the technical head of the project. The goal of the project is a very flexible unit that can be used worldwide and therefore will be able to dismantle aircraft anywhere around the globe – independently of its airworthiness.

An important part of this attempt is a good preparation and comprehensive planning of each dismantling project. From a dismantler's point of view the first important challenge is to detect any hazardous material within the aircraft to enable protection-routines for the staff and to avoid any environmental impact. For that reason a process was developed to change a hazardous structure like an aircraft into a non-hazardous compound and by doing so prepare the aircraft for the recycling process. The designed process is intentionally very close to the end-of-life vehicle ordinance in Europe [2]. Through the eyes of a recycler a car and an aircraft are very much alike. Although an aircraft is more complex and expensive than a car the approach for recycling is very similar.

In Europe, waste is legally organized in the “Guidelines on the Application of the Waste Catalogue Ordinance” (Abfallverzeichnis-Verordnung - AVV) [3], where every waste has a number according to its production. In our case, 160104*, “End-of-life vehicles (ELV), hazardous components and parts as listed in group 1601 below” [3]. Waste marked with an asterisk is a dangerous waste for which a special treatment is regulated by law. The target is to handle the recyclable material with the focus on the European Closed Substance Cycle and Waste Management Act [4].

The process’ aim is to convert the material into material as defined by waste-number 160106, “End of life vehicles, containing neither liquids nor other hazardous components”. As such, it can be treated unproblematically in a beneficiation process to separate the different materials. This is important to process the laminated composites into a secondary raw material. The following figure 2 shows these processes as an adaption from the according flow-chart for ELV.

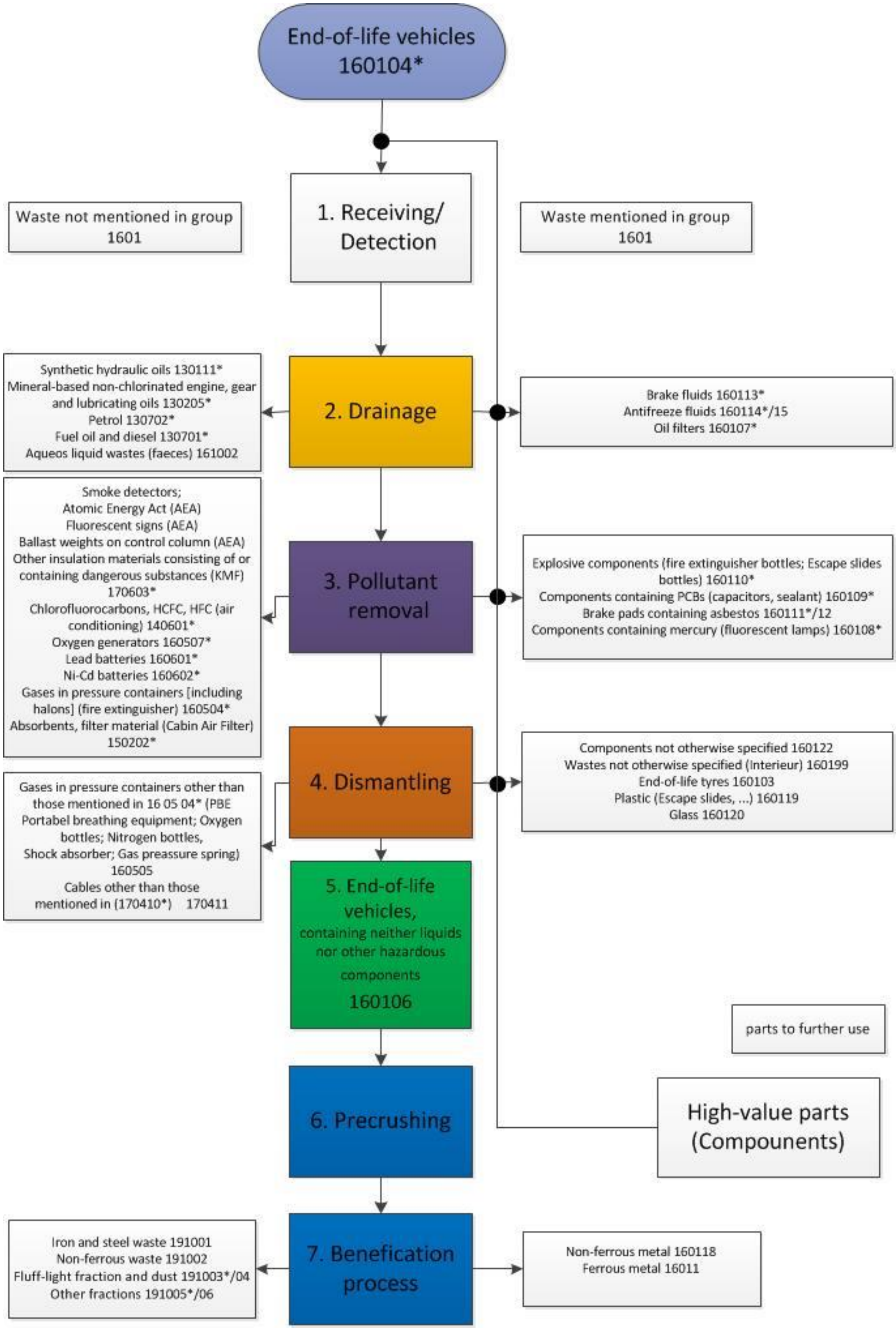

Figure 2: Recycling Process for end-of-life vehicles

Receiving/Detection

One of the main topics trying to take over an end-of-life-aircraft is to clarify the ownership of the aircraft and its parts. Before the work can start it is important to ensure that the planed recycling process will report to the according authorities. The customer or the customers (in case that the plane or parts of the plane is owned by more parties) is obligated to sign a de-registration form. Only with this de-registration letter the dismantling company can start the recycling process. In Germany the aeronautical supervising authority is the LBA, in Europe it is the EASA, in America the FAA, etc. The document of withdrawal or respectively the aviation incapability is issued by the respective country. Of further importance is the condition of the aircraft, which parts are included and how many fluids are inside. A specific work scope for every project is inevitable.

Another important prerequisite is the provision of a suitable dismantling area. In most cases this will be a part of an operational airfield and therefore one has to comply with a number of aviation related regulations. The dismantling area needs to have at least a closed concrete pavement for the dismantling activities. In addition to that, it must be ensured that no light weight material gets blown away by any wind turbulences. This is guaranteed through a two-meter-high movable fence around the dismantling area. In addition to this, it is helpful to know the main wind direction and the distance to the runway. It is also inevitable to include the fire service of the airport and other airport authorities, especially the environmental and security officer in the project to discuss their additional requirements. For this process, it is profitable when the dismantling company has special expertise and experience for the on-site work at an airfield. This needs of course a specially trained team for the dismantling of the aircraft. For example a safety engineer, radiation adviser, explosive adviser, etc..

A major practice-oriented support will give the Best Management Practice 3.0 (BMP) made free available by the non-profit organization Aircraft Fleet Recycling Association (AFRA). This is a very well-developed guideline for the end-of-life management of old aircraft. It is recommendable to make an accreditation by the AFRA when companies work with old aircraft and try to recycle them. This is the accepted industrial minimum standard for handling old aircraft.

Drainage and ventilation

An aircraft consists of several hazardous liquids that have to be handled carefully. Table 1 gives some examples with the corresponding European waste codes for disposal.

Table 1: Hazardous fluids contained in an aircraft and their European waste codes

Fuel oil and diesel	130701*
Brake fluids	160113*
Antifreeze fluids	160114*/15
Oil filtres	160107*
Synthetic hydraulic oils	130111*
Mineral-based non-chlorinated engine oils	130205*
Petrol	130702*
Aqueous liquid wastes (faeces)	161002*

A Boeing 747-300 can be fuelled with over 200.000 litres of kerosene. This makes a separate tank necessary for defueling. For reasons of corrosion and weight balancing, the airplanes in storage mode are generally fully fuelled. To empty the tanks, a defueling station with probes is used (see figure 3). After this procedure, the tanks must be force-ventilated with compressed air. To ensure a non-explosive atmosphere in the tanks, gas analyses from within the tanks are taken during and after the force-ventilation.

Figure 3: Defuelling unit [Keske Entsorgung GmbH]

Another important issue is the handling of the pressured hydraulic oil systems. The system has to be depressurized and the liquids have to be stored in special containers (see figure 3). For the presented liquids with an asterisk a record of waste disposal of these presented liquids with an asterisk is necessary. The record of waste disposal is a resilient document to proof, that the waste is orderly disposed.

Pollutant removal

After having removed the fluids, other hazardous materials have to be taken out manually. Special attention has to be turned to the radioactive parts. These parts are treated under the Atomic Agency Act and therefore are not itemised as waste in European regulations. It is of almost importance to ensure that experienced expert personnel handle the following hazmat materials. Another issue is the record of waste disposal for these following materials. The best way to handle this is the path of the Manufacturer's Serial Number.

Table 2: Hazardous non-liquids in an aircraft and their European waste codes

Explosive components	160110*
Components containing PCB	160109*
Brake pads containing asbestos	160111*/12
Components containing mercury	160108*
Insulation Materials (KMF)	170603*
Chlorofluorocarbons, HCFC, HFC	140601*
Oxygen generators	160507*
Lead batteries	160601*
Ni-Cd batteries	160602*
Gases in pressure containers (Halon)	160504*
Absorbents, filter material	150202*
Smoke detectors	Atomic Energy Act (AEA)
Fluorescent signs	Atomic Energy Act (AEA)
Ballast weights on control column (seldom)	Atomic Energy Act (AEA)

For example glass fibre that has been manufactured before 1995 is very toxic according to Asbestos “Index of substances which can cause cancer, genetic changes or limit reproductive capability, TRGS 905” [5]. This requires special equipment for the employees working with this kind of material. It is important that they wear protective clothing (anti-static), work boots (anti-static), gloves, special masks, helmets and safety glasses for their work.

Figure 4: Part out of mineral fibre

Dismantling

It is noticeable that the following table has fewer codes with an asterisk (see Table 3). This is the process step where all the interior parts, tires, glasses etc. are sorted. Unfortunately, at present, it is not possible to recycle the plastics and composites. For the moment being, the material is treated as refuse incineration. The positive effect is that it is possible to make energy from this material (Cardboard, plastics, polyurethane foam, wood etc.). The problem is the low mass because of the necessary logistic to a treatment facility that is capable of using this specific material.

If it works to create a big aircraft recycling hotspot, then the plastic and carbon fibre recycling approach from aircraft is possible. First experience with plastics are being made at present at the Fraunhofer Institut, Pfinztal and at carbon fibre recycling facility of the Karl Meyer AG in Wischhafen with a low temperature process in Germany or the University of Nottingham in England with cooperation with Boeing. A post-industrial recycling is possible but it is a challenge to concentrate so many materials at the dismantling area that it is profitable to recycle these lightweight materials at present. The biggest challenge is the factor of logistic costs for the material to pass to a recycling company that can handle these specific materials and make profit with them.

Table 3: Material list from removing the interior of an aircraft

Cables containing oil	170410*
Cables	170411
Glass	160120
Plastic (Escape slides)	160119
End-of-life tires	160103
Wastes not otherwise specified (Interieur)	160199
Components not otherwise specified	160122
Gases in pressure containers	160505

In the following (see figure 5), some examples of the safety equipment in an aircraft is given. In figure 5 a parted out and kindled escape slides. First procedure step is to part out the gas cylinders and the batteries, cut the slides with a cutter knife and dispose the plastics. The life vests process is very close to the slide process. The difference is the storage energy in this systems. An uncontrolled escape slide could cause massive damage for life and limb due to an inappropriate handling.

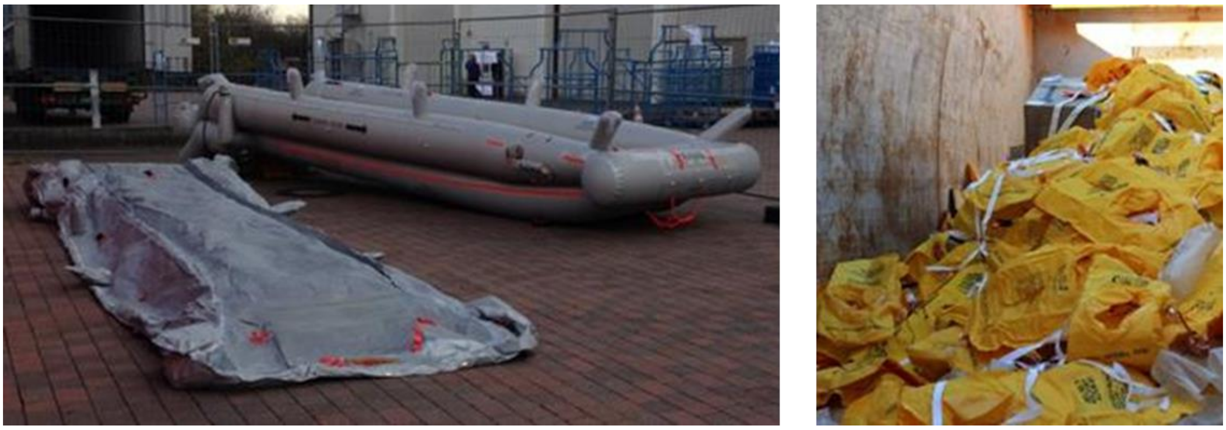

Figure 5: Kindled slides and vests

The target of the developed process is to treat the equipment in a manner that makes it possible to change the European waste number from 160104* to 160106 by according procedure. With this waste number (160106) it is possible to take the next process step being the pre-crushing at the dismantling area and the following beneficiation process for that material. That means the aircraft is ready for cutting and the next recycling step.

Pre-crushing

The final step at the airport is the pre-crushing of the aircraft and the transfer to the recycling facility for the beneficiation process. Before the pre-crushing process starts, a second gas check takes place to ensure a non-explosive atmosphere. If the analysis is positive and there is no threat of an explosion from fuel, the cutting process starts. At first the excavator cuts the vertical stabilizer to reduce the aerodynamic drag to the airplane from wind and to ensure a better stability. The next step is the cutting of the wings and then the excavator cuts towards the centre tank section (see figure 6).

Figure 6: Cutting off of the vertical stabilizer and the wing

The pre-crushed parts are directly loaded into containers to reduce the danger of wind-blown dispersal of light-weight material. The customer gets a proof of waste with a complete dismantling certification and a complete documentation of the process. This is labelled with the registration marks and the specific MSN of the aircraft. This is an important step to prevent unapproved aircraft parts (Bogus parts).

Mobile Unit

Considering the global locations where inoperative aircraft are stored today, it was already mentioned that these will hardly be on the European continent. Humidity and general weather-conditions make a long-term storage of old aircraft in Europe utterly implausible. Furthermore, old aircraft will rarely make their last flight within Europe. Due to the strict requisites on safety and maintenance in Europe, old aircraft today are often transferred to the African continent or South-Asian continent for follow-up usage. Getting those aircraft back is not an option, so the logical alternative is to disassemble and pre-crush those planes on-site and transport the parts to a suitable industrial scrap metal processing plant.

While the pollutant removal and dismantling has no need for heavy machinery, the pre-crushing process does need an excavator with grab and cutter. Due to the very specific requirements for aircraft pre-crushing, it would be an additional difficulty to rent this equipment in the destination country. In a project, supported by the Federal Ministry of Education and Research (BMBF), the above mentioned consortia started a project to assemble a mobile unit for aircraft pollutant extraction, pre-crushing and to identify ways for beneficiation and reuse of the materials (MORE-AERO). The unit consists of two containers filled with a grab and a cutter mounted on a quick-change system for multiple excavator-systems as well as everything else needed to dismantle an aircraft. Additionally, it holds tank-containers to safely remove liquids from the aircraft. Figure 7 shows the loaded unit.

To ensure safe and fast customs procedures the logistic associate of the project STUTE Logistics (AG & Co.) KG is developing a best-practice for a number of countries with strategic importance. Included in those considerations are legislative framework conditions, regional cooperation arrangements and on-site-handling of material and equipment.

Figure 7: The Mobile Unit from the MORE-AERO-Project

Beneficiation process

Following the exemplary recycling-route of a car the next steps would include pre-crushing, shredding and sorting of the material. As a continuation to figure 2 figure 9 shows how this process should be extended to meet the requirements of the multiple materials from aircraft-recycling. While in car-recycling the steps of shredding and post-shredder-technologies are sufficient, post-shredder technologies for aircraft-shredder residues is of more importance, as the major part of materials are non-iron materials.

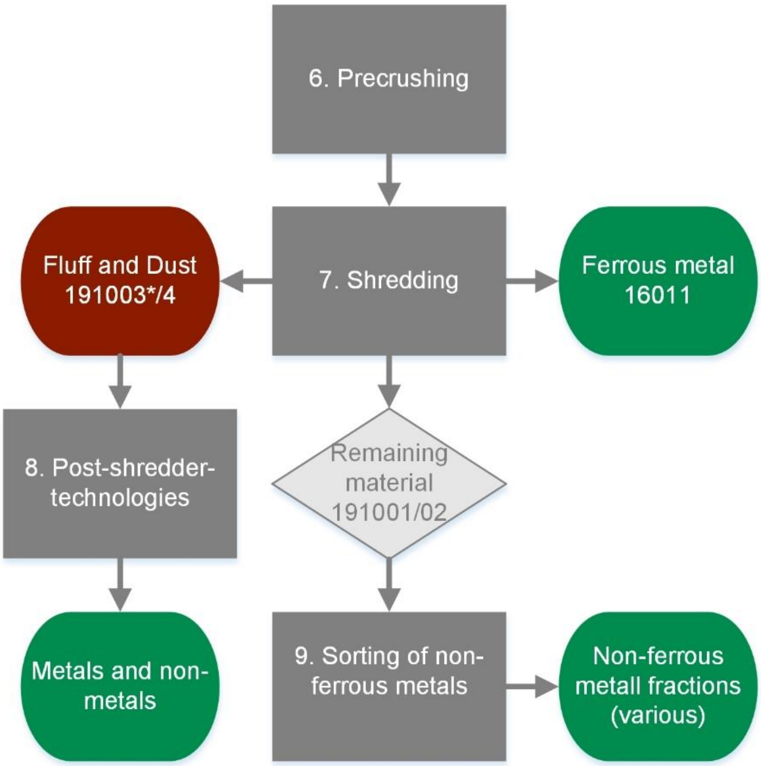

Figure 8: Stages for aircraft recycling adapted from car-recycling

For all materials used in beneficiation the knowledge of the used joining technologies is essential. Potential vulnerabilities can be exploited to separate assembled parts. But unlike cars, aircraft have multiple joining technologies in use. Parts in an aircraft can be joined by studding, glueing, welding and soldering. Figure 9 shows an example for highly complex material joining. Analyses have identified two different aluminium alloys (Al1 and Al2), one iron based material (FeX) and titanium (Ti). The two Al1-sheets are closure-sheets, Al2 is part of a structural component. Both are glued and riveted (iron based rivet) to each other. To protect the rivet head from mechanical and other contact stress it is plated with a titanium sheet, which is glued.

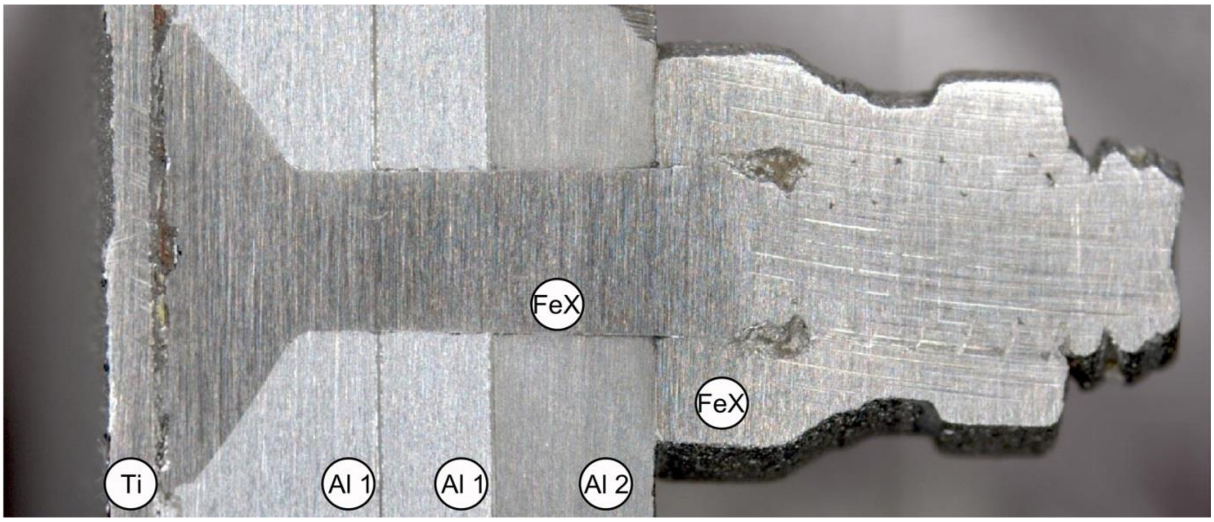

Figure 9: Part of aircraft with three layers of aluminium (Al1 and Al2), an iron rivet (FeX) and a titanium sheet (Ti)

The main materials of aircraft currently considered for recycling are aluminium alloys (2000 series and 7000 series), steel, titanium, copper, plastics, carbon fiber, etc.. Especially the mentioned aluminium alloys need specialized recycling routes, if the material is to be reused in a high quality process. The aluminium for example cannot be used for the steel production as deoxidation aluminium. With regards to its low standard potential (E0) of -1,66 V, aluminium is considered a base metal. The alloying copper from the 2xxx-alloy group cannot be extracted with state-of-the-art beneficiation-processes. The result for the iron industry could be red brittleness. Removing these impurities is at the moment only possible with complex and costly procedures like chlorination or vacuum distillation. So the aim of a beneficiation process for aircraft recycling should not only be the separation of main elements, but an in-depth separation even amongst alloys.

Already smallest errors can result in off-specification batches that result in lower to lowest market prices.

At the moment, the separation of metals from recycled aircraft is done on a metal group base (Al-based, Fe-based, Cu-based etc.). But for a higher quality it is of utmost importance to collect and handle the accruing material by its composition down to the level of the alloying constituent. To give an impression of the used materials in old aircraft (1980's) Figure 10 gives an overview of the used materials.

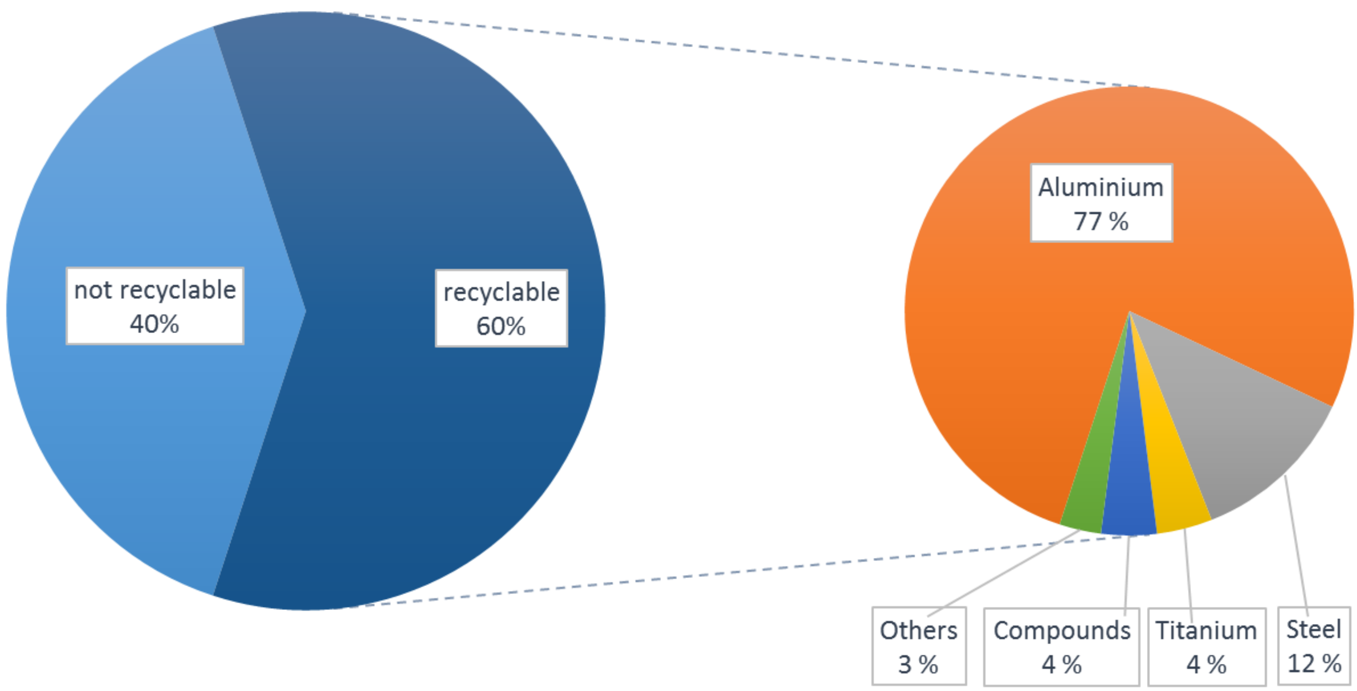

Figure 10: Material in an aircraft from a recycler point of view

Having in mind that 77 % of recyclable material from an aircraft is aluminium, the first aim in the MORE-AERO project was to identify state-of-the-art beneficiation processes for aluminium. At the moment most aluminium is recycled by re-melting it in melted salt furnaces. The quality of the product of these furnaces highly depends on the input materials. Therefore the corresponding refiner and remelter industry differentiate between cast and wrought alloy input due to the low and high alloys.

To further improve the beneficiation of aluminium alloys, the first line of approach is to identify respective sorting systems to separate even different aluminium-alloys. Systems capable of distinguishing between different aluminium alloys could be laser breakdown spectroscopy (LIPS), X-ray transmission or respectively, X-ray fluorescent systems and sorting systems using YAG-lasers.

With this approach three levels of recycling leading to three different output qualities were defined:

1. Low-level-recycling is the state-of-the-art way to treat aluminium scrap. The material is used as input material for melted salt furnaces and can be tailored by charge make-up
2. Mid-level-recycling uses a more specific input by means of alloy-varieties to produce a better product
3. High-level-recycling extracts mono-fraction material for specialised refiners

As much as the knowledge of the used joining technologies is important for a suitable beneficiation processes, the knowledge of the exact materials is also crucial to identify suitable commercialization for the materials. Therefore a large-scale data-acquisition has to be realised. At this moment, 889 different materials (by specification-nr.) used in one single airplane are analysed.

With the identification of suitable recycling routes a first step is taken, to close the material-loop of aircraft. But more research has to be made to find every aspect to manage a high level recycling of every aspect of an aircraft.

Conclusion

The recycling of obsolete aircraft can only work when the whole end-of-life management trades work hand in hand. That should start at the first audit with the estimation of an old aircraft. It goes on with a professional de-pollution of the aircraft. That means, the described way from AVV160104* to a good material handling AVV 160106 without an asterisk. This ensures an environmentally friendly process. Figure 2 shows the process proposal with the whole European waste numbers depicted.

Professional de-pollution induces high cost, thus it is important that the customer develops a feeling for the complexity of hazmat materials. Our recommendation is that the aircraft producers support a professional recycling after an aircraft's life. This would be possible through an enhanced product liability.

For the retreatment of materials from old aircraft the recycling-process of end-of-life-vehicles can be adapted to a certain extend. But to ensure high quality recycling, the particular characteristics of the build-up and the materials from the aircraft need to be taken into consideration. Therefore the identification of used materials is as important as the identification of possible routes for the re-use of the material especially from an economic point of view. Only if every aspect of the recycling of an aircraft is taken into consideration an economically viable model for the recycling of end-of-life-aircraft can be achieved. With the project MORE-AERO a first step is taken and suitable recycling routes for the aluminium-parts have been identified.

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