DEVELOPMENT OF THE PEEN FORMING PROCESS FOR SPHERICAL SHAPED COMPONENTS

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ABSTRACT

The main tank H-155 of ARIANE 5 containing cryogenic propellants is built of weldable Al-alloy 2219. With its size (diameter 5.4 m) the tank exceeds all tanks for launchers built in Europe for the time being.

For forming the spherical shaped segments of the tank bulkheads of the ARIANE 5 launcher, different forming processes, like spin forming, stretch forming and peen forming were investigated.

The reasons, which have led to the application of the peen forming process for forming the segments, will be described in the following paper; further, the development of the peen forming strategy and the process parameters will be referred to.
With respect to parameters and contour measurement, great efforts were required to reach the desired high form accuracy of the components.
The expectations on the formed material have been very high and the properties achieved in the segments will be reported in this paper. For the forming process a new computer-controlled peen forming machine was built and qualified.
Finally the technique and the possibilities of this machine will be explained briefly.

KEYWORDS

Peen forming, spherical shaped components, forming methods, Al-alloy 2219, peening parameters, peening strategy, material properties, residual stresses, peen forming machine.

INTRODUCTION

Dornier began, some ten years ago, to use the shot peen forming of NC-machined parts, like the alpha jet wings, a stringer-reinforced fuselage skin of the Airbus A 310 and a stringer-reinforced frame segment of the water tank of the 1st stage of the ARIANE 4 [1], [2], [5]. In contrast to Mc Donald Douglas and Boeing as we know, Dornier is using large steel balls for peen forming.

With the development of the ARIANE 5 launcher H-155, Fig. 1, Dornier received the order for the development of the bulkheads out of the weldable aluminium alloy A 2219. These bulkheads close the cylindrical part of the launcher upward and downward, and they contain the connections for the tanking-pressurizing and ventilating pipes. A further bulkhead in the upper quarter of the cylindrical part devides the oxygen from the hydrogen tank.

The bulkheads have a diameter of 5.4 m and are welded together from 8 individual segments (Fig. 2). This large diameter requires high precision and quality concerning the manufacturing process.

After studying different processes for forming the spherical shaped segments of the tank bulkheads of the launcher, Dornier decided for the peen forming process.

As the aforementioned parts of the Airbus A 310 and the ARIANE 4 were only cylindrical shaped the segments with their spherical shape needed a new development concerning the peen forming process.

In the following paper, a survey is given about the development of shot peen forming and production of the components of the tank bulkheads.

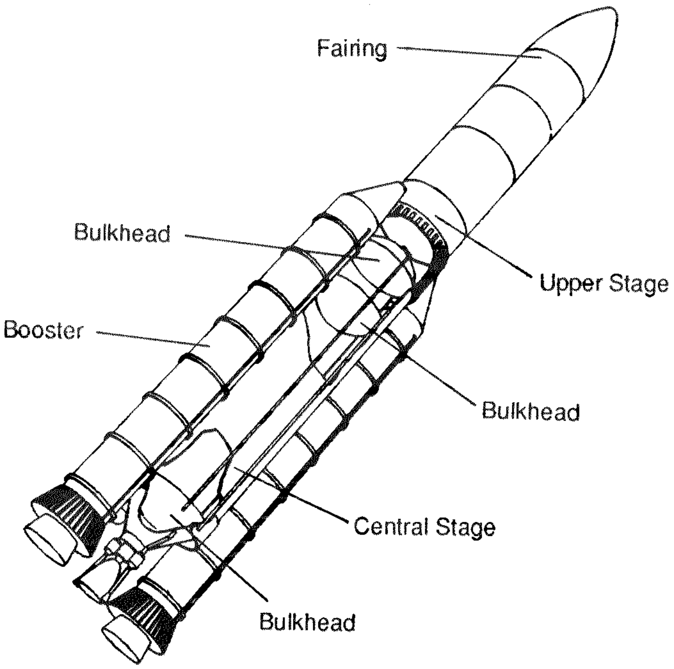


Fig. 1: ARIANE 5 Launcher

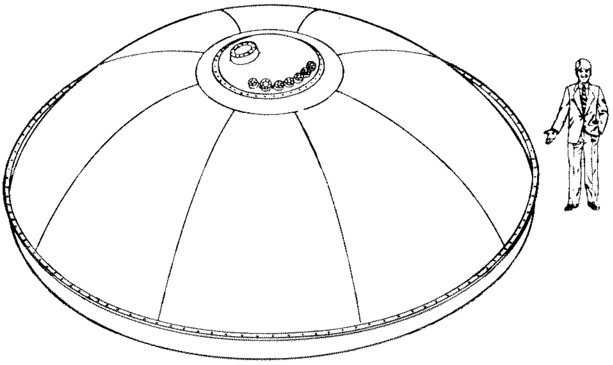


Fig. 2: Tank bulkhead of ARIANE 5

CHOICE OF THE FORMING METHOD

For forming the segments of the tank bulkheads different forming processes like spin forming, stretch forming and peen forming were investigated under the aspects of feasibility, technical risks and influence on the costs.

Spin forming was already used for forming the tank bulkhead of the ARIANE 4. However for the large bulkhead of ARIANE 5 with 5.4 m ø there were no sheets available with a width of 6 m. Therefore it was necessary to combine two sheets with an aiding weld seam to a round plate of 6 m diameter. In pretests the round plate with the weld seam was spin-formed at a temperature of 160°C. But the pretests did not lead to success because the weld seam failed before reaching the necessary depth of the bulkhead.

Further stretch forming, which is a proved method in aircraft industry, was tested. As there was no stretch forming press with sufficient capacity to form the sheets of 2219 in the temper T31 it was necessary to do the forming in two steps. In the first step the segment is preformed in the soft temper and, in the second step, it is completed after solution heat treatment.

After forming, the segments have to be milled chemically to get the necessary milling steps in the segments (the welding border has a higher wall thickness then the inner field of the segments).

Because of the high requirements on the tank bulkheads concerning the tolerances and the strength Dornier decided for the peen forming process. By achieving optimal mechanical properties the lowest possible wall thickness and, by this, the lowest mass shall be realized.

The reasons for this decision were different significant advantages of the peen forming process, e.g.:

- forming in precipitation hardened temper T87 without any heat treatment
- forming with milling steps (mechanical milling instead of chemical milling)
- highest mass saving
- high flexibility concerning changes in form and wall thickness
- low number of production steps

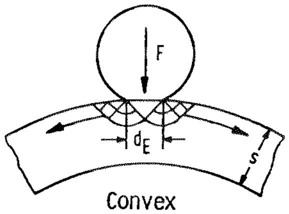
In a development program, which was ordered by CRYOSPACE, Les Mureaux, and carried through in cooperation between Dornier Friedrichshafen and Munich, IBF (Institut für Bildsame Formgebung), ECMF (Engineering Consulting Metal Forming, Aachen, the procedure of peen forming the segments was tested and optimized.

PEEN FORMING OF THE SEGMENTS

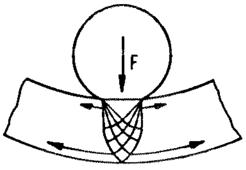
PEENING STRATEGY

Fig. 4 shows the local sheet metal thickness and the outer dimensions of the segments to be shaped. These dimensions do not result from shaping aspects, but have been elaborated by optimizing strength criteria and weight savings. A relatively thin-walled, homogeneous sheet metal area is thus surrounded by a thicker, more stable frame.

For this component and, in particular, for this material it was necessary to select suitable peening parameters. For this purpose, a multitude of downscaled metal sheets was peen formed with different parameters and measured subsequently. In addition, sheets of different thickness values were treated with various shot velocities to determine the working points "maximum convex curvature", "maximum concave curvature", and the point inbetween where only "elongations with the sheet remaining plane" were generated (Fig. 3). When the appropriate peening parameters for the internal area of the segment were known further peening parameters and process steps had to be elaborated to achieve the elongation gradients in the marginal area.



Convex



Concave

Fig. 3: Achievable curvature by peen forming [4]

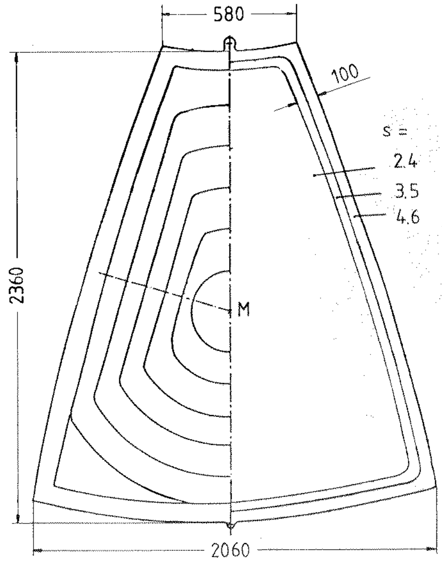


Fig. 4:
Geometry of tank bulkhead segment and masks along "lines of constant strain".

Before the actual component could be peen formed fixtures had to be developed which enable an appropriate constant tension of the component. Moreover, a technique to generate the required gradient of the shot distribution over the segment surface had to be elaborated, to achieve the sheet metal elongation corresponding to the geometry.

After a series of different tests, clamping the segment into a special fixture, which holds the component elastically in a concave position (Fig. 5 and 6), turned out to be a suitable method. Masks as shown in Fig. 4 and 6 were used to distribute the peen forming energies over the component. These masks were necessary because the peen forming chamber was not equipped with the required control systems.

By combining almost all possibilities applicable in peen forming, such as convex peening, concave peening, homogenizing, prebending, prestressing and by the corresponding measuring control of the components with the measuring device (Fig. 7) it became possible to manufacture reproducible components by this process, which fullfil the requirements concerning the general shape with a tolerance of ± 1,5 mm from the nominal radius of 3000 mm.

Fig. 8 shows the first welded tank bulkhead with peen formed segments.

In the meantime, a new peen forming machine, constructed and built by Baiker AG, Zurich, has been installed at Dornier (Fig. 9). This plant works with a continuous pressure peening system and a gravitation-injection peening system. The nozzles are moved by a 5-axis CNC-unit, which is suspended on chamber ceiling. The movements of the work piece are possible by a desk turnable in 2 axes. The plant is equipped with a regulating unit for the shot mass flow and an automatic shot reclaimer. Further the plant has a unit which separates the shot according to shape and geometry as well as different tanks for different peening media.

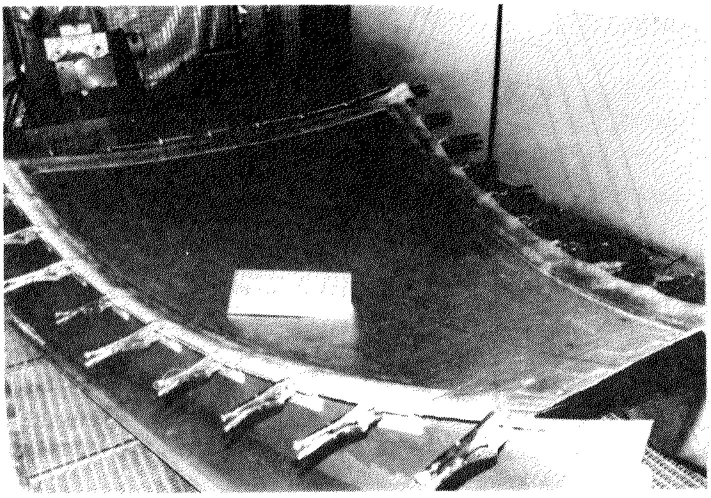


Fig. 5: Tank bulkhead segment fixed on templates in the peen forming chamber

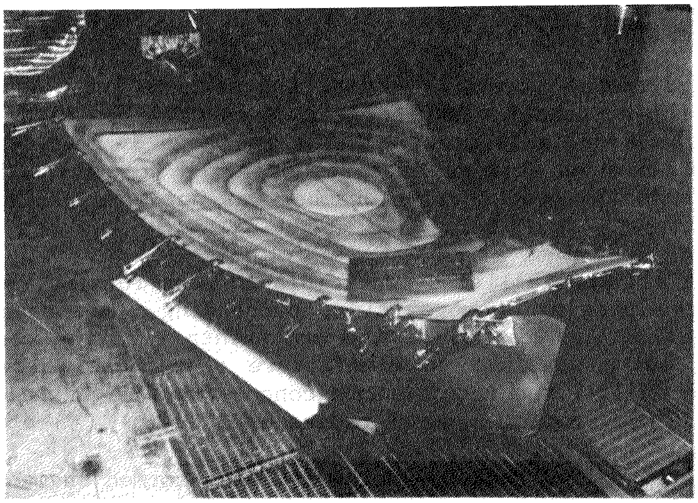


Fig. 6: Arrangement of peening masks on the concave segment surface

The described plant offers the possibility of generating three-dimensional, numerically controlled peening paths. The following step consists in manufacturing components with this plant without applying the mask technology. Initial results will probably be presented on the occasion of the next lectures in Tokyo scheduled for the autumn of 1990.

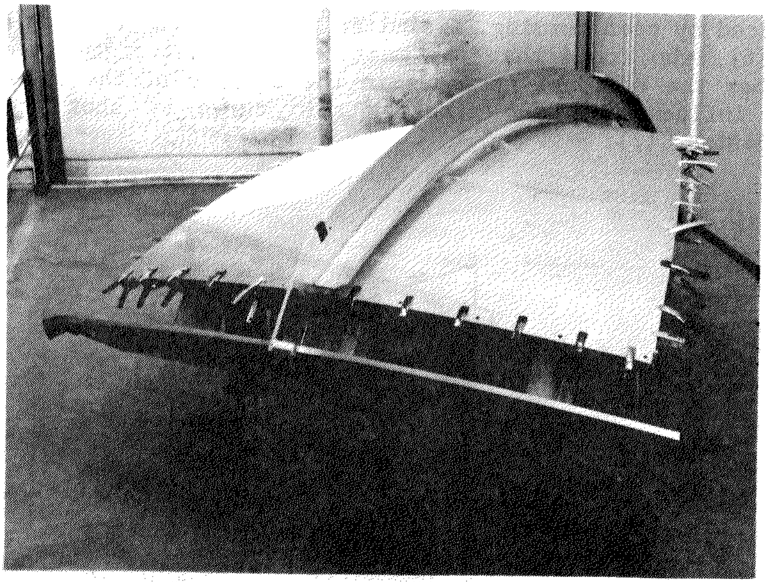


Fig. 7: Bulkhead segment on the measuring device

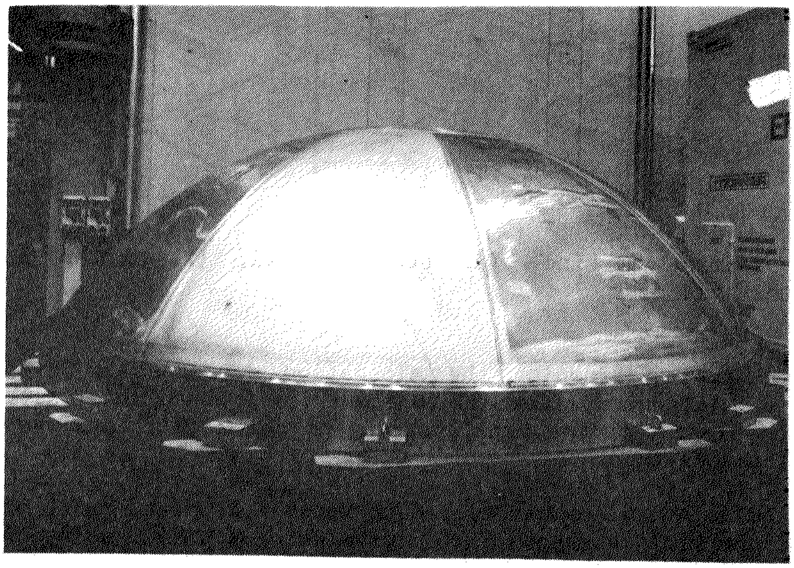


Fig. 8: Welded tank bulkhead with peen formed segments

INFLUENCE OF PEEN FORMING ON THE MATERIAL PROPERTIES

Part of the qualification program was to prove the material properties, like mechanical strength, corrosion behaviour, crack propagation and the residual stresses. Material samples from different parts of the segments with different coverage were tested. The increase in tensile strength depends on the coverage. With increasing coverage up to about full coverage (98 %) the strength increases and then, with higher coverages, the strength decreases (Tab. 1 and

Fig. 10). The decrease can be explained by the supperposition of the residual stresses introduced by peen forming. A similar behaviour was already described by O. Kienzle [6], who found that the measured yield strength becomes more reduced the higher the residual stresses in the surface of the material have been. A direct influence on the stress strain curve by shot peening was measured by B. Deffner [7].

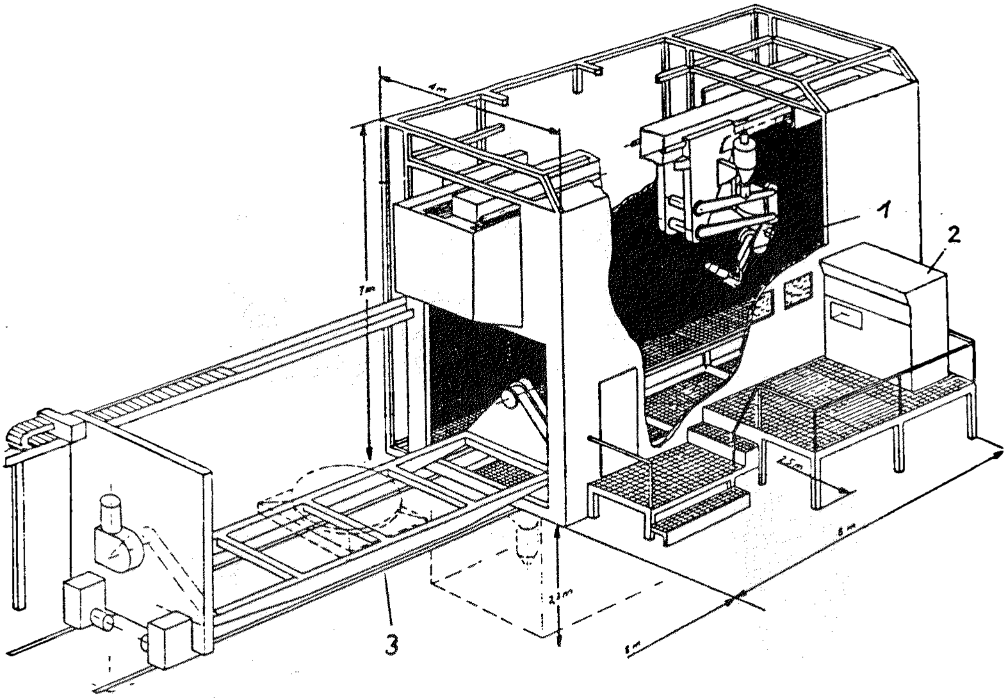


Fig. 9: Peen forming machine, (1) peening head, (2) controlling desk, (3) turnable desk

Because of the strain hardening the elongation decreases with increasing coverage from 10 % (unpeened material) to about 7 % (peened material). For improvement of the elongation the manufacturing of the 2219 sheets was modified to get higher formability.

The stress corrosion behaviour was tested on tensile samples, which were loaded with 75 % of the yield strength for 30 days using 3 % NaCl solution similar to the standard LN 65666. None of the test samples failed because of stress corrosion cracks.

The K_c-value and the crack propagation velocity were measured on CCT-samples. Because of the lower ductility in the peen formed segments the K_c-value was about 16 % lower than in the unformed sheets, Tab. 1.

The residual stresses were measured in dependence of the depth. On the concave side compressive stresses of about 100 N/mm² were measured and on the convex side low tensile stresses of about 30 N/mm². Also after chemical polishing to half the sheet thickness low compressive stresses were found.

Tab. 1 Material properties before and after forming of 2219 T87

	before forming	after forming*	nominal value according QQ-A-250/30
R_m [N/mm²]	480	509	442
$R_{p0,2}$ [N/mm²]	399	451	359
A %	10.5	7.2	6.0
K_c [N/mm³/²]	1891	1580	

* The values are mean values measured in the middle area of a segment.

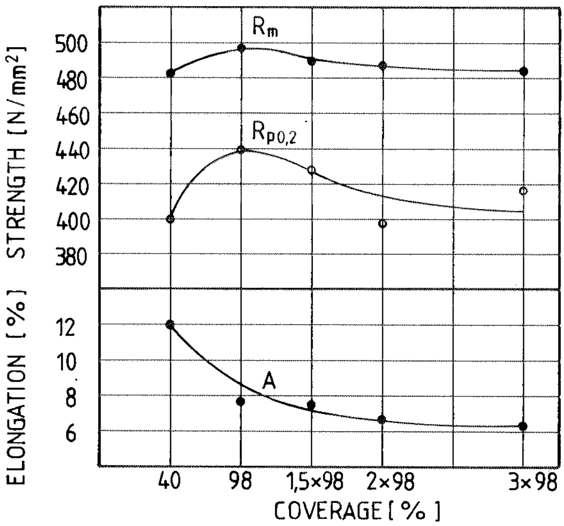


Fig. 10: Mechanical properties of 2219 sheets versus coverage, shot peen formed in temper T87

APPLICATION TO OTHER COMPONENTS IN AIRCRAFT AND SPACE INDUSTRY

The experience gained in peen forming spherical shaped components could also be applied to modern launcher systems, like e.g. EARL or SÄNGER or the European shuttle HERMES. These launcher systems and flight systems contain partially or totally winged reusable stages. The number of complex formed components is high. So, the peen forming process could be applied not only to the tank structure but also to parts, like wings, tail plane, fuselage, or nose section. Especially parts which are stringer-reinforced could be formed by peen forming.

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