Aluminium Mirror Technology at ESO: Positive Results Obtained with 1.8-m Test Mirrors

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The aluminium alternative for the manufacturing of astronomical mirror blanks developed initially around the NTT project. A series of tests on 500-mm samples [1] led to the conclusion that a 4-metre-class aluminium mirror was feasible [2], with a similar level of quality as a glass mirror. This option was seriously considered for the NTT active primary mirror but finally canceled because of schedule problems. In addition to being much less expensive than glass, aluminium also presents advantages [3] such as reduced fragility, easy machining, possible repair and excellent thermal conductivity. The latter almost eliminates the risk of thermal gradients (in normal operation) and would improve the efficiency of thermal control (mirror seeing). The main problem is that few data on long-term stability exist. Since 1968, Merate Observatory runs a 1.4-m telescope with an aluminium primary. Measurements carried out by ESO in 1982 showed a total aberration of less than 1 fringe, well within the spatial frequency range of an active support.

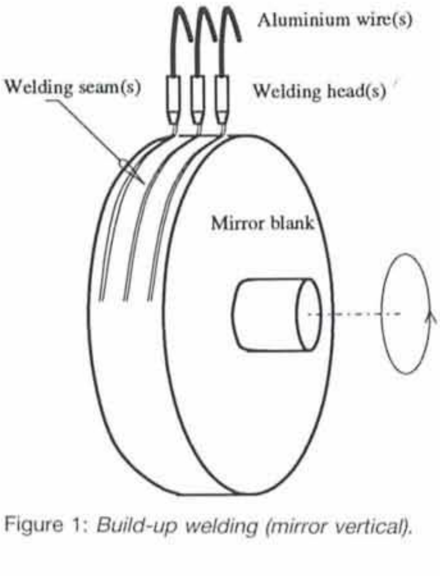

Figure 1: *Build-up welding (mirror vertical).*

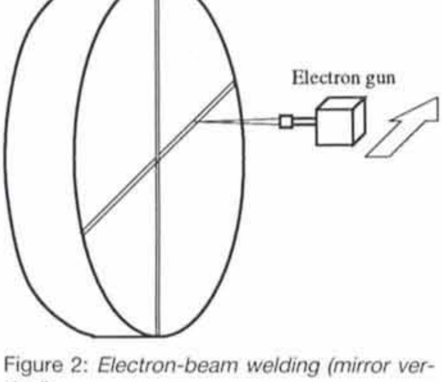

Figure 2: *Electron-beam welding (mirror vertical).*

Development continued within the framework of the VLT programme [4]. Since the technology selected for the NTT (casting) does not seem extrapolable above four metres, different manufacturing processes had to be investigated. Initial tests on 500-mm samples led to the selection of two promising techniques: build-up (BU) welding and electron-beam (EB) welding. It was consequently decided to pursue investigations on intermediate-sized blanks of 1.8 m diameter.

Two blanks were purchased, one from Linde (Germany, build-up welding) and one from Telas (France, electron-beam welding). The principles of both technologies are shown in Figures 1 and 2. Build-up welding consists in building up the complete aluminium piece by continuous deposition of a welding seam. After selection of the proper alloy and optimization of the welding parameters, excellent homogeneity of the crystalline structure and extremely low porosity could be achieved. Although this technique is well known with steel and applied to pieces in the 10-m dimension range (pressure vessels), it was surprisingly less known by most aluminium manufacturers. A picture of a 500-mm build-up aluminium mirror blank is shown in Figure 3. Electron-beam welding is a well-mastered welding technique which consists of fusing pre-assembled pieces by means of an electron gun of sufficient power. The technique is well mastered in industry and the demand for scaling the technology up to large diameters already exists (naval construction). The pieces to be assembled can be cast, forged or rolled. An appreciable advantage of EB welding is that no extra material is introduced which reduces the risk of inhomogeneity. For the manufacturing of an astronomical mirror the most interesting process is to weld forged segments, since forged aluminium pieces show excellent homogeneity and very low porosity. A picture of the 1.8-metre EB welded mirror blank shortly after welding of a radial joint is shown in Figure 4.

All problems encountered at the blank manufacturing stage could be efficiently solved, and no limitation could be found in a possible extrapolation to 8 metres. Independently of the ESO activity, experiments in the 8-metre range are carried out in the framework of the Eureka-funded LAMA project (Large Active Mirrors for Astronomy, INNSE/TECNOL, Italy, with REOSC/ONERA, France, under TELAS management). Two 4-metre-long segments which will repre-

Figure 3: *Build-up welded aluminium blank of 500 mm.*

Figure 4: *1.8-m aluminium blank shortly after welding of a segment.*

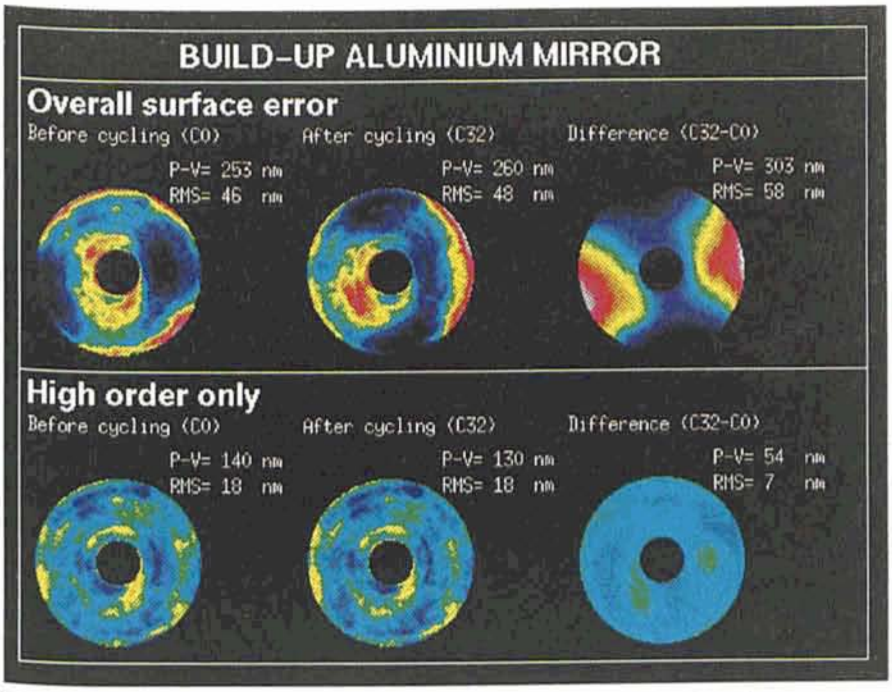

Figure 5: *Surface maps of the BU welded mirror before and after thermal cycles.*

sent 2/16 of an 8-metre mirror blank will be EB welded.

After manufacturing, the 1.8-metre blanks received thermal treatments which included annealing and cryogenic stabilization. After machining, the blanks were 1.8 metre in diameter, 300 mm thick, with a flat back and a f/1.67 spherical concave surface (within an accuracy already in the micron range, thanks to computer-controlled machining).

Both blanks were shipped to Reosc (France) for optical figuring. Rough grinding was followed by nickel coating, subcontracted by Reosc to Tecnol (Italy). Nickel coating consisted in the deposition of a nickel layer by a chemical process. The thickness of the layer is in the range of 0.1 mm. A nickel coating is required because aluminium is not directly polishable, at least within the same level of cosmetic quality as glass or nickel. After nickel coating the mirrors were fine ground and polished spherical, with a radius of curvature of 6 metre (f/1.67). Because of the innovative aspect of the experiment, ESO required that emphasis be put on the accuracy of surface measurements instead of the accuracy of the optical surface itself. However, both mirrors were polished well within specifications and according to Reosc, there would be no problem in achieving the same standards of quality as with glass. For what concerned bubbles and inclusions, both aluminium blanks were comparable to glass blanks. After polishing the effect of these bubbles and inclusions on the optical surface was totally negligible. The high expansion coefficient of the substrates did not cause significant problems, neither did the bimetallic effect between the aluminium and the nickel.

In polishing nickel coated aluminium mirrors, the danger is not with the adherence of the nickel layer but with the risk of breaking through the nickel coating, which required that the thickness of the coating be monitored. This risk emphasizes the requirements on accurate machining prior to coating, and on the uniformity of the nickel layer.

After acceptance of the mirrors, their stability towards ageing was checked. Thermal cycles followed by interferometric tests at centre of curvature were ordered from Reosc. One cycle consisted in varying the temperature from ambient temperature down to −20 degrees centigrade, then up to 40 degrees and back at ambient temperature, within about 24 hours. Both mirrors underwent 32 cycles, with intermediate checks after 4, 8, and 16 cycles.

The final results are summarized in Figures 5 and 6, which show the surface maps before and after 32 cycles. Surface errors were measured interferometrically at centre of curvature with a sampling of about 8000 points on the mirror (100 points across a diameter). The surface maps presented in Figures 5 and 6 result from the averaging of 50 interferograms each; the standard deviation is about 1 nanometre on the RMS surface error. Even on knife-edge images, no fine structure linked to the welding seams could be detected.

The most important figures are the variations of the surface errors rather than their absolute values, and above all the variation of high order effects, defined as surface errors after the 3rd and 5th order optical aberrations have been mathematically removed. While variations of the surface error function are observed, the global optical quality remains stable. The variation of the surface errors (axisymmetrical for the Telas mirror, astigmatic for the Linde) are less than one fringe and would be fully compensated by a simplified active support. They were detected after the first inter-

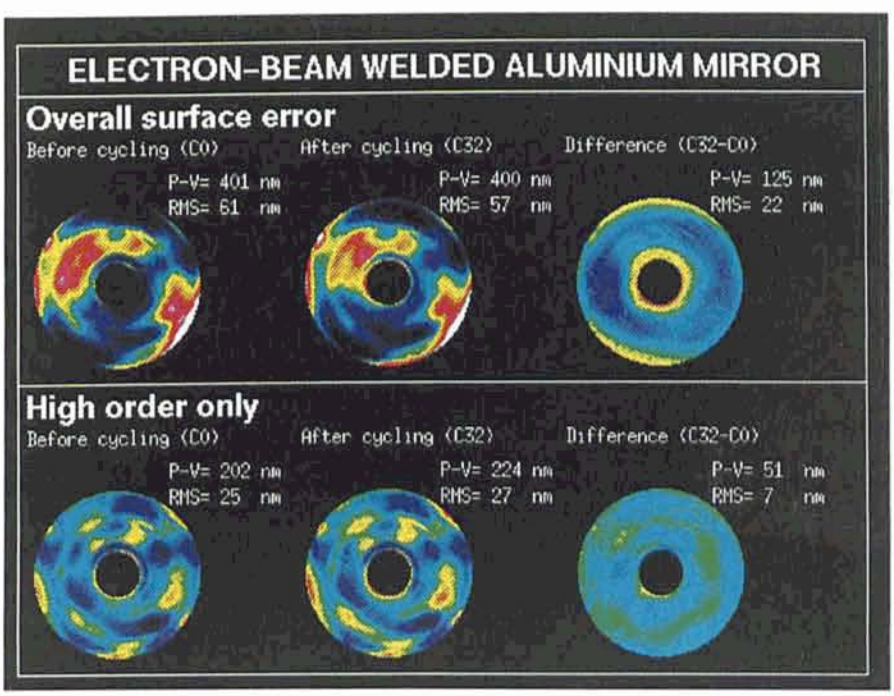

Figure 6: *Surface maps of the EB welded mirror before and after thermal cycles.*

mediate measurement (four cycles) and remained stable. High spatial frequency errors remained almost perfectly stable.

The conclusion is that in visible light (λ=500 nm) the stability of both mirrors towards ageing cycles is of the order of λ/25 for the overall rms surface errors and λ/70 for the high spatial frequency rms surface errors, a very positive result. Moreover, the changes occur during the first cycles and the surfaces remain almost perfectly stable afterwards. A question still open is the homogeneity of the coefficient of thermal expansion (CTE). Although the effect of possible inhomogeneities in the range of 1 to 5% of the nominal CTE (a very generous tolerance) could probably be compensated with active optics (unless they are very localized), a definite answer should preferably result from a series of tests at different temperatures.

This experiment has brought great confidence in the aluminium mirror technology. Both technologies, BU and EB welding, proved adequate for the manufacturing of 2-metre-class astronomical mirrors. Not only were the optical tests very successful, even more important is the fact that extrapolation to larger diameters now seems possible.

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ESO, the European Southern Observatory, was created in 1962 to . . . establish and operate an astronomical observatory in the southern hemisphere, equipped with powerful instruments, with the aim of furthering and organizing collaboration in astronomy . . . It is supported by eight countries: Belgium, Denmark, France, Germany, Italy, the Netherlands, Sweden and Switzerland. It operates the La Silla observatory in the Atacama desert, 600 km north of Santiago de Chile, at 2,400 m altitude, where fourteen optical telescopes with diameters up to 3.6 m and a 15-m submillimetre radio telescope (SEST) are now in operation. The 3.5-m New Technology Telescope (NTT) became operational in 1990, and a giant telescope (VLT=Very Large Telescope), consisting of four 8-m telescopes (equivalent aperture = 16 m) is under construction. Eight hundred scientists make proposals each year for the use of the telescopes at La Silla. The ESO Headquarters are located in Garching, near Munich, Germany. It is the scientific-technical and administrative centre of ESO where technical development programmes are carried out to provide the La Silla observatory with the most advanced instruments. There are also extensive facilities which enable the scientists to analyze their data. In Europe ESO employs about 150 international Staff members, Fellows and Associates; at La Silla about 40 and, in addition, 150 local Staff members.

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