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Materials Irradiation Experiments for the SNQ-Target

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Abstract

Commercial AlMg3 and AlMgSi, both in a high strength and an annealed condition have been irradiated

a) with 760 MeV protons to a fluence of 3.2×10^{20} p/cm^2 yielding a calculated radiation damage of 0.2 dpa (<u>d</u>isplacement <u>p</u>er <u>a</u>tom) and 67 appm He.

b) with 28 MeV He^{++}-ions yielding 170 appm helium.

Tensile tests at RT, 100°C after helium implantation and at RT, 100, 200, and 300°C after p-irradiation show

a) no influence of p-irradiation on the 0.2% flow stress and the ultimate tensile strength of the annealed materials.

b) in case of the hardened alloys those values are reduced to those of the annealed alloys

c) no significant influence of helium implantation on tensile data.

1. Introduction

In case of the proposed german spallation neutron source (SNQ) the spallation neutrons will be created by a proton beam characterized by an energy of 1.1 GeV and a time averaged current of 5 mA. Because of the high heat deposition by the beam the target was designed as a rotatable wheel (Fig. 1) carrying a few thousend individually cladded targetelements cooled by water. Those elements will be build of tungsten, uranium or, as a back-up material, lead.

Different Al-alloys as AlMgSi or AlMg3 are favourable to the general structure of the target wheel and to the cladding of these materials. The advantages of these materials are

- high thermal conductivity, i.e. low thermal stresses
- low neutron absorption
- fast decaying neutron induced activity
- low void
- well known technology

The importance of these properties underlined by regarding the conditions for SNQ-operation:

- Creation of radiation damage
- production of large amounts H of helium mainly by (p,)-reactions
- introduction of thermomechanical stresses due to the heat deposition by the p-beam and
- fatigue

A material research program has been established to examine the material behaviour under conditions close to real SNQ operating conditions /1/. This paper reports some results of this program.

2. The influence of helium implantation and proton irradiation on the mechanical properties of two Al-alloys.

We compared, by tensile testing, the 0.2 % flow strength and the ultimate tensile strength of specimens without any pretreatment, after helium implantation and after p-irradiation.

Two different Al-alloys were used: AlMg3 and an AlMgSi-alloy (US Al 6061). Both alloys, delivered as sheets of 0.5 mm thickness, were rolled to foils of 250 μm thickness. In order to establish a hardened (abbreviation h) as well as a soft (abbreviation s) condition of these materials, they were heat treated in the following manner.

AlMgSi (h)	-	annealed for 15 minutes at 530°C, quenched in water.
	-	aged for 16 hours at 160°C (precipitation hardening)
AlMgSi (s)	-	annealed for 3.5 hours at 380°C
AlMg3 (h)	-	no heat-treatment (cold-worked)
AlMg3 (s)	-	annealed for 3.5 hours at 350°C

After this treatment specimen of the geometries as shown in Fig. 2 and 3 were punched out of these foils.

2.1 Helium implantation: IBES

A He^{++}-implantation was carried out using the SNQ-irradiation chamber IBES (Ispra Bestrahlungsexperiment SNQ) at the compact cyclotron of CCR Euratom, Ispra (Italia). A schematical sketch is given in Fig. 4.

IBES consists mainly of the following details. A beam window separating the vacuum of the cyclotron from the cooling helium gas in the chamber, a rotatable beam stop also serving as an aperture in the open position, a degrader wheel made of Al-foils of different thickness allowing to implant the specimen homogeneous through their thickness and the sample clamped on a water cooled holder. The Al-alloys were irradiated at 100°C with 28 MeV-He^{++} particles at beam currents of 2.5 µA leading to a nominal helium content of 170 appm after 3 hours. A thermal release measurement yielded 158 ± 13 appm He. The standard deviation of 13 appm has been determined by thermal release of 3 different specimens. These data are in good agreement with the nominal ones.

2.2 The proton irradiation SNQ

The proton irrediations were carried out 1983/84 in Los Alamos at the ISORAD the facility at LAMPF, (Fig.5), which was the only one available at this time.

To transport the specimen to the irradiation position they had to be first transferred from a cask to a cart, then from the cart to stringers. This procedure didn't allow to have a dynamic temperature measurement. To minimize corrosion effects and to assure good heat transfer 7 of the samples were packaged in an Al envelope and sealed (Fig. 6).

16 of these envelopes were then placed in a water cooled specimen holder as shown in Fig. 7.

The irradiation parameters are listed below:

Temperature 40-50—C (calculated; certainly not exceeding 100—C)
Proton energy: 760 MeV
Beam spot: gaussian profile, $2\sigma \sim 5$ cm
Average beam current: 570 µA
Irradiation time: 705 h
Fluence: 3.2×10^{20} p/cm^2
radiation damage: 0.2 dpa (calculated)
He-content: 67 appm (calculated)

2.3 Tensile testing

An Instron Typ 1122 tensile test machine with a temperature cabinet was used to determine the 0.2% flow strengh and the ultimate tensile strength as a function of temperature (23 and 1oo°C in case of the He^{++}-implanted specimen and 23, 100, 200 and 300°C in case of the p-irradiated materials). All specimen were tensile tested with a strain rate of 2.8×10^{-4} sec^{-1}.

3. Results

Fig. 8-11 show the measured dependence of the 0.2 % flow strength and the ultimate tensile strengh from the testing temperature for Al 6061 and AlMg3, respectively. The soft canditions are denoted with "S", the hardened conditions by "h".

The symbols and their meaning are summarized in Tab. 1.

Taking into account the different geometry of our specimens, we have two references in both conditions and materials - one denoted by "LAMPF" (reference for the p-irradiated samples) and another one denoted by "KFA" (reference for He^{++}-implanted samples)

Table 1:

Symbol	Tensile testing	after
*	"LAMPF"-reference	(h)
H	"KFA"-reference	(h)
+	p-irradiation	(h)
y	He^{++}-implantation	(h)
x	"LAMPF"-reference	(s)
#	"KFA"-reference	(s)
0	p-irradiation	(s)
8	He^{++}-implantation	(s)

One recognizes (by comparison of the symboles # and 8) that helium implantation does not influence the tensile properties in case of the soft alloys. Tensile testing proves that p-irradiation does only slightly affect these properties (x and 0). This is true - within the experimental errors being about 10% - for all test-temperatures. In case of the hardened alloys, however, we have a different situation. While helium implantation does not affect the 0.2 % flow strength and the ultimate tensile strenght (H and Y) after p-irradiation a strong reduction of the mechanical properties is observed (* and +). Moreover - by comparison of the symbols + and 0 one sees, that this reduction leads to the values of the soft alloys.

4. Discussion

The most suprising result is the p-irradiation induced loss of strength in case of the hardened materials. Normally one would expect an irradiation induced hardening as has been published by Farrell and King /2/ in a paper about the tensile properties of neutron irradiated 6061-Al alloy in annealed and precipitation hardened conditions.

The irradiation was performed at 55°C to fast ($E > 0.1$ MeV) fluences up to 1.8×10^{27} n/m^2 and thermal ($E < 0.025$ eV fluences) up to 7.0×10^{27} n/m^2 yielding a radiation damage of 260 dpa. The results were that the 0.2 % flow strength and the ultimate tensile strength raised by 45 to 60%. The explanation given by the authors was that this hardening was caused by creation of 7 wt% Si from transmutation reactions.

This result suggests:

a) n-irradiation is not comparable with p-irradiation

b) different microstructural processes become effective under p-irradiation.

References

/1/ W. Lohmann: ICANS VII, Proceedings of the 7th International Collaboration on Advanced Neutron Sources, Chela River Nuclear Laboratories, 1983, Sept. 13-16, Chalk River, Ontario, Canada, p. 274-78. "Irradiation effects in candiate materials for the SNQ"

/2/ K. Ferrell, R.T. King: "Tensile Properties of Neutron Irradiated 6061 Aluminium Alloy in Annealed and Precipitation Hardened Conditions", Effects of Radiation on Structural Materials A51M-51:, 683 61979) 440.

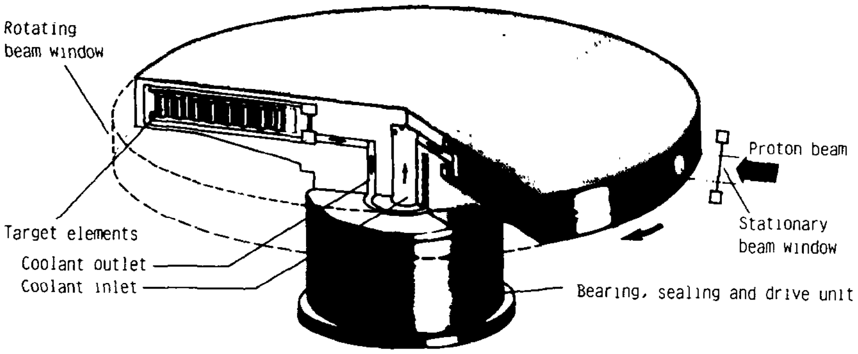

Fig. 1: The SNQ-target wheel

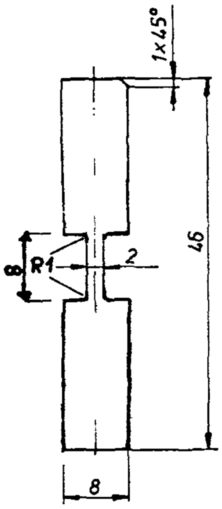

Fig. 2: Geometry of specimens used for helium implantation (all dimensions in mm), thickness = 0.25 mm

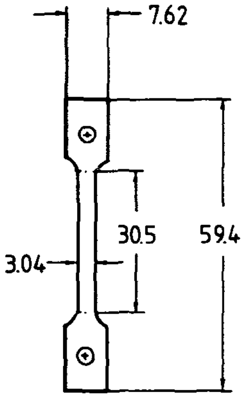

Fig. 3: Geometry of specimens used for p-irradiation (all dimensions in mm, thickness = 0.2 - 0.3 mm)

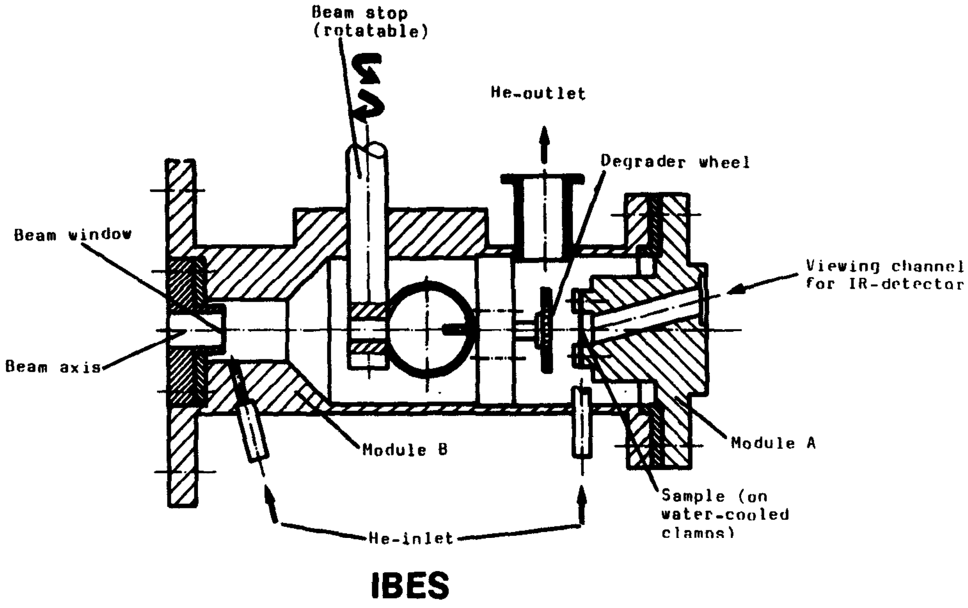

Fig. 4: The irradiation chamber IBES (schematically)

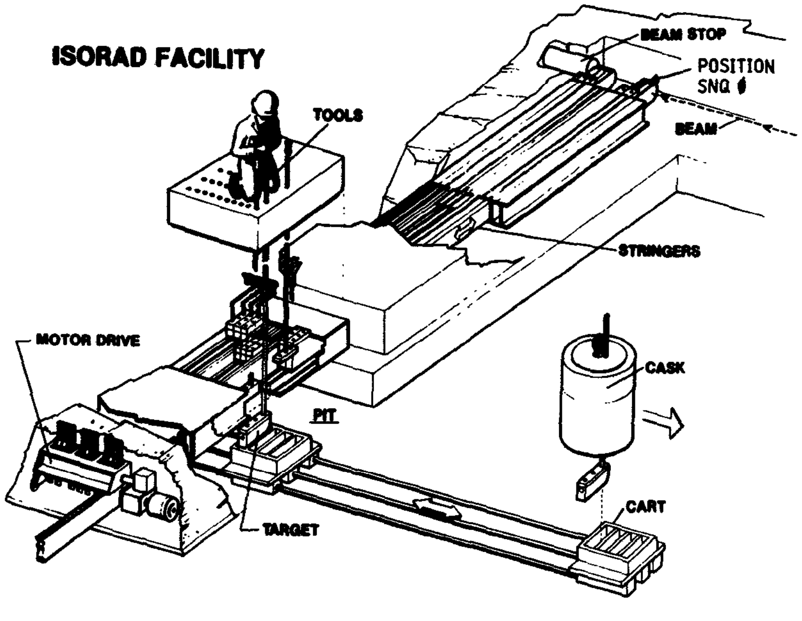

Fig. 5: The LAMPF isotope Production Facility

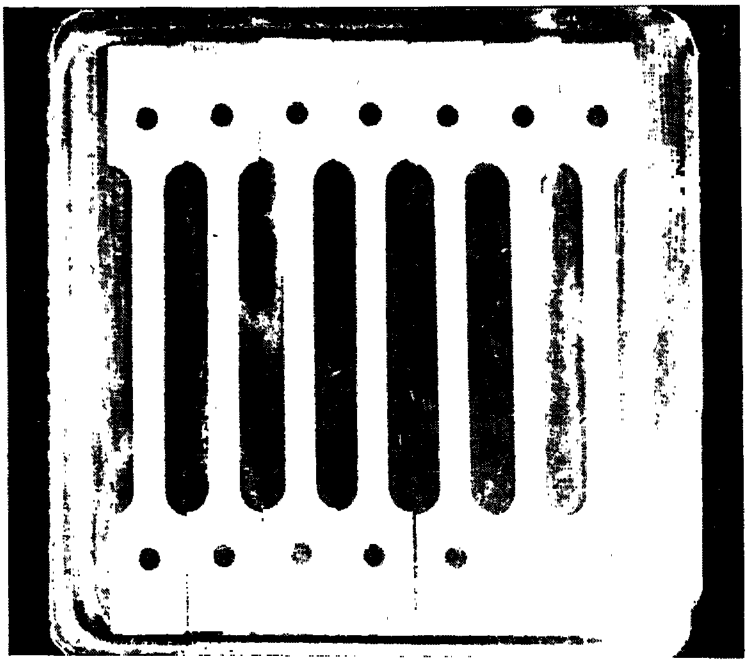

Fig. 6: SNQ 0 samples in the open envelope

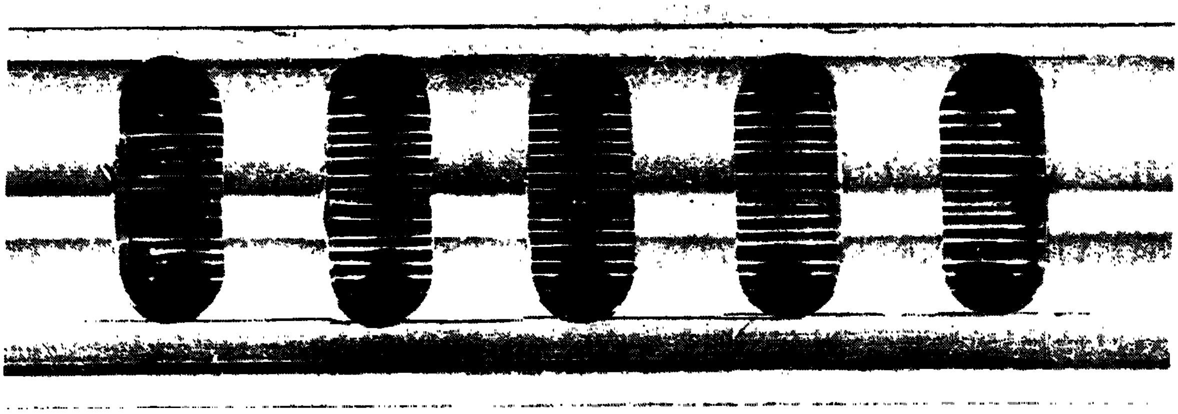

Fig. 7: The SNQ-0 specimen holder

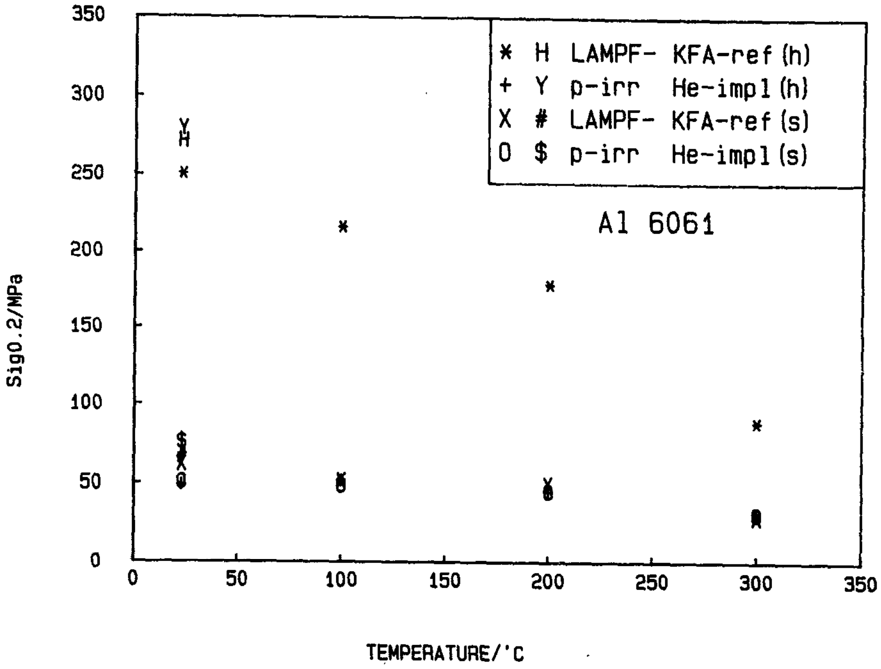

Fig. 8: Temperature-dependent 0.2 % low stress of Al6061 (anneald and percipitation hardened) unirradiated, He^{++}-implanted and 800 MeV-protron irradiated.

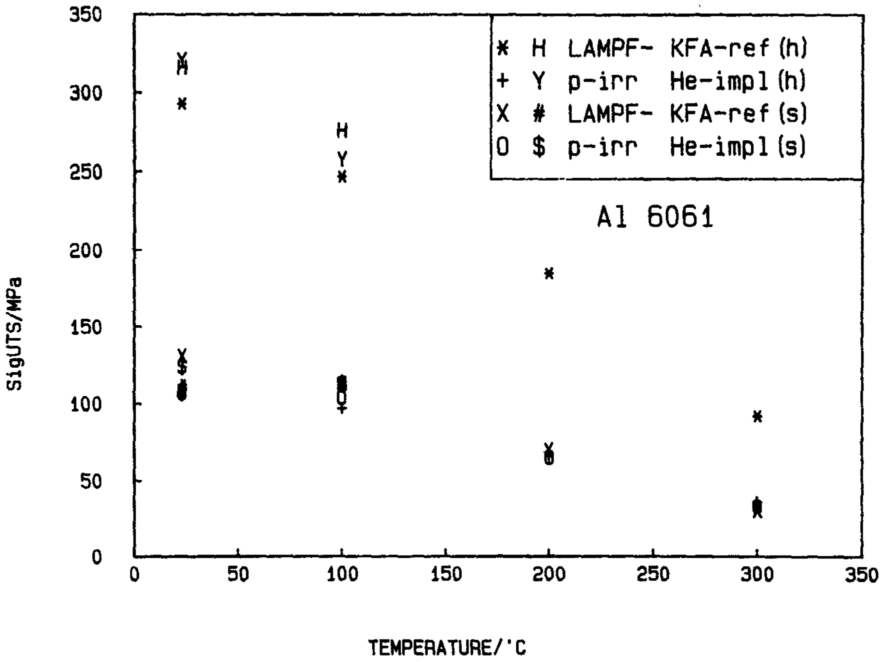

Fig. 9: Temperature-dependent ultimate tensile strength of Al6061 (annealed and percipatation hardened) unirradiated, He^{++}-implanted and 800 MeV-proton irradiated.

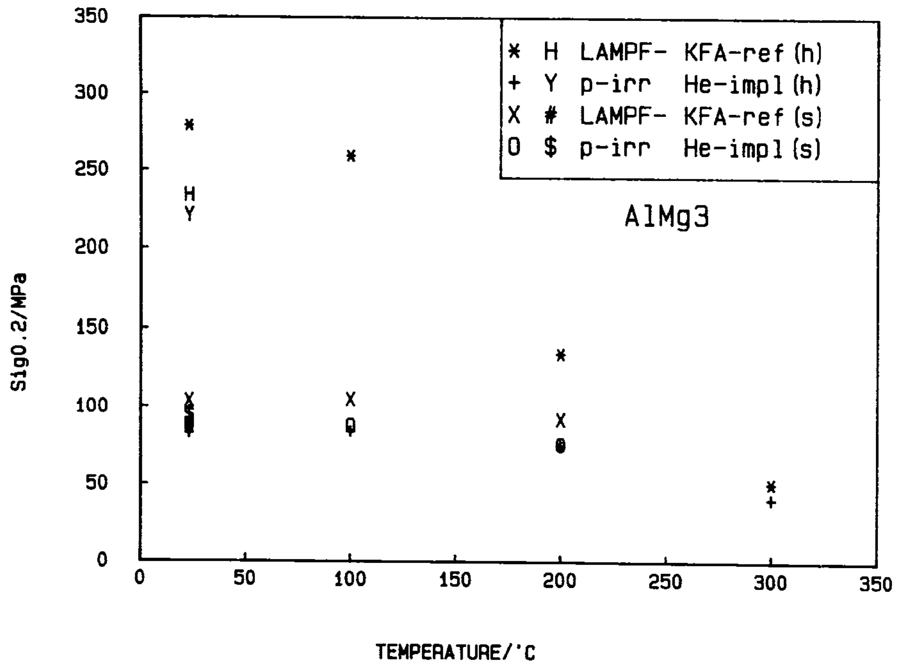

Fig. 10: Temperature dependent 0.2% flow stress of AlMg3 (annealed and cold worked) unirradiated He^{++} implanted and 800 MeV proton irradiated.

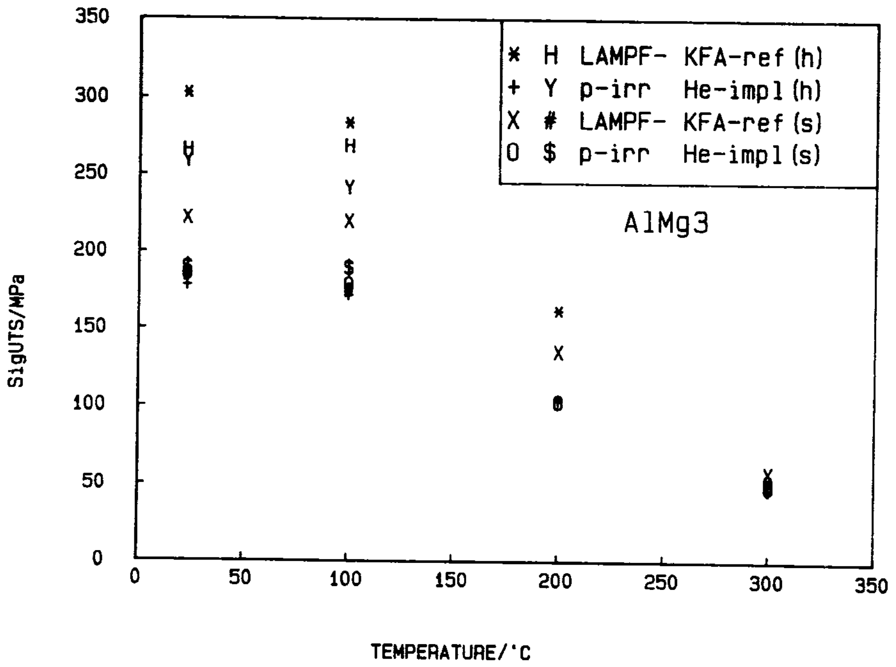

Fig. 11: Temperature dependent ultimate tensile stress of AlMg3 (annealed and cold worked) unirradiated He^{++} implanted and 800 MeV proton irrdiated.