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STRESS CORROSION FAILURES IN REFORMER FURNACE COMPONENTS*

by

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SUMMARY

The present article describes the repeated and unusual occurrences of stress corrosion failures at the top inlet material components of the primary reformer furnace in an Ammonia Plant. Experience in repair and remedial actions to reduce such incidence of failure is also discussed in this paper.

INTRODUCTION

Madras Fertilizers Limited, India, operates a 750 MT/day Ammonia Plant. Catalytic reforming of steam hydrocarbon mixture is the process adopted for the manufacture of ammonia. The reformer furnace is of Haldar Topsoe (Denmark) design and has two radiant side-fired furnaces. The steam naphtha mixtures are passed thru vertically kept reformer tubes inside the reformer furnace.

Each reformer furnace has 120 reformer tubes - 6" ODx15/16" thick. The reformer tubes are fed from inlet headers thru inlet pigtails and the reformed gas leaves thru outlet pigtails connected to bottom collectors. Steam-naphtha mixture (4.5:1) enters the reformer tubes at 35 kg/sq.cm and 450°C.

Reformer furnaces require heat resistant high alloy castings and wrought nickel-chromium alloys. Centrifugally cast heat resistant alloy HK 40 is one of the most widely used material for the reformer tubes operating upto 950°C. The reformer tubes in Madras Fertilizers Ltd. are made of centrifugally cast HK 40 alloy (25 Cr, 20 Ni, 0.4% C). This material has excellent creep rupture properties, good corrosion resistance against attack by furnace gases. and a difinite economic advantage over similar wrought iron-chromium-nickel alloys.

In our case the reformer tube terminates, at the top, in a HK-40 stub-end. The stub-end has a loose carbon steel flange which is boltedto the inlet hair-pin tube (fig. 1) The inlet hair pin tube extended, in the original arrangement, about 18" inside the reformer tube. The inlet pig-tails and reformer top stub-ends are outside the reformer furnace roof.

HISTORY OF FAILURES

In 1974, after 3 years of operation, during pressure testing after new catalyst loading, we observed leaks in some of the reformer tube top stub-end welds. Subsequent inspection revealed extensive cracking both longitudinal and circumferential-in the reformer tube stub ends (HK-40) and inlet pigtail (SS 321) weld cap welds. Such cracking in reformer furnace components is considered unusual although similar instances of failures have been experienced in a few steam-naphtha reforming furnaces elsewhere, in mid'60s and early'70.

Detailed metallurgical examinations were done on the cracked reformer tube stub end (HK 40) and inlet pigtail (SS 321). The failed stub end and inlet pigtail weld cap exhibited both transgranular and intergranular mode of cracking (fig. 2 and 3). Both the longitudinal (transverse) and the circumferential cracks originated at the inside surface and at the heat affected zone (HAZ) of the parent materials. Many of the longitudinal cracks extended to both sides of the weld. The circumferential cracks originated at the interface of the top weld layer and HAZ at the I D., and propagated to the top layer of weld in the transverse (thickness) direction.

Predominant transgranular cracking in both the reformer tube stub-end and inlet pigtail weld-cap led to the conclusion that failure was by stress corrosion cracking. Presence of intergranular cracking observed along with transgranular cracks suggested that both chloride and caustic stress corrosion cracking could be the mechanism for the massive failures. Small traces of chloride and alkali present in the steam entering the reformer furnace was considered the possible source of corrodent. Residual weld stress was also the cause for both longitudinal (transverse) and circumferential cracking.

Repair welding of used reformer components is often considered difficult because of the micro-structural changes associated with high temperature operation and also because those changes make it difficult to adopt the same original manufacturing welding procedure. In our case, repair welding was done using high nickel-chromium filler wire and electrodes (Inconel 82 and Inconel 182). Most of the cracked HK 40 stubends were replaced with

Inconel-600 (72 Ni., 16 Cr., 7 Fe.) alloy because of its known resistance to chloride stress corrosion cracking and also due to its ready availability.

In 1976, after 21 months of operation since repair welding and replacing most of the reformer tube stub ends with Inconel-600, we experienced a similar cracking problem in both the HK-40 tube HAZ and the inlet pigtail weld cap. Repeated condensation, concentration of high temperature chloride and/or caustic, in the empty zones above the reformer furnace was considered the mechanism of the stress corrosion failures. To overcome this, the inlet pigtail arrangement was modified.

A notable exception, in the 1976 failure, was that the Inconel-600 stub ends did not develop any cracking. We, therefore, replaced all the remaining HK-40 stub-ends with Inconel-600 adopting the same repair weld procedure done in 1974.

In January 1978 - 14 months after replacing the stub ends in all 240 tubes with Inconel-600 and modifying the inlet pigtail assemblies, we experienced a similar large scale longitudinal and circumferential stress corrosion cracking. This cracking, however, was significantly different from the previous failures and was found mostly in the high nickel Inconel 600 stubs only. Stress corrosion cracking by high temperature caustics and high left-over weld stress was considered the mechanism for the Inconel 600 stub end failures.

CORRECTIVE MEASURES

Having experienced three similar failures in 4 years with different materials and design modifications to the top inlet reformer components, we considered several proposals to prevent this occurence.

Several questions which arose were:-

i. How to prevent contact of welded HK 40 and Inconel-600 from high temperature chlorides and or caustics present in steam and what methods would be realistic and economically justifiable.

ii. Would stress relieving of the top stub end welds (between used HK-40 tube and Inconel-600/HK-40 stubs) considerably bring down the residual stresses and reduce the chances of stress corrosion cracking and if so what are the practical difficulties in performing a high temperature stress relieve annealing.

iii. Would lowering the concentration of the corrodents by process improvements reduce the risk of such failures.

iv. Would any other preventive method against direct impingement of the corrodents in the weld zones be possible and the relative success of such method.

On careful examination of these alternatives, stress relieving the weld areas heldout much promise and was adopted.

High nickel-chromium-iron or iron-chromium-nickel alloys are not routinely subjected to thermal stress relief as a part of the manufacturing procedure. Insufficient service data on the success of such stress relieved HK-40 and Inconel alloys in reformer service and the practical difficulties involved in the heat treatment discouraged us from attempting this alternative during the earlier failures. However, in January 1978, we experimentally stress-relieved some welds of HK-40 and Inconel 600 at 870°C and installed these in service. These experimentally stress-relieved repair welds did not develop any cracking in seven months exposure when inspected in September 1978, whereas the as repaired welds developed stress cracks similar to the three earlier failures (1974 - 78).

Having identified the role of residual weld stresses in the severity of the cracking, we experimentally studied and evaluated the effects of various heat treatment and welding parameters. Figures 4 and 5 show the yield stress vs. temperature curves for cast HK-40 and Inconel-82 filler wire. Inconel-82 values are similar to Inconel-600. From these curves, it is clear that Inconel-600 alloy has higher yield strength than HK-40. For our design temperature (450°C), the residual weld stress may become approximately 36,000 psi (2530 kg/sq.cm) for HK-40 and approximately 45,000 psi (3760 kg/sq.cm) for Inconel-600.

X-ray stress analysis was done to know the effect of heat treatment for different heating and cooling cycles. Maximum relief in residual stresses was attained when heat treated at 980°C with slow cooling. We also estimated the residual stresses in the machined edge of the tubes prior to welding. To our surprise, the machining stresses due to grinding, cutting, turning were found to be as high as 40% of the yield stress of the materials. In order to safeguard against possible chances of introducing excessive machining stresses, the machined tube ends were also mill-annealed at 980°C prior to welding.

From our experience high nickel alloys like Inconel 600 (72 Ni, 16 Cr) did not have a significantly higher stress corrosion resistance against attack by elevated temperature caustics. Therefore, in September 1978 when we had to replace the stub ends as the old ones had become short due to repeated cutting and rewelding we reverted to HK-40 stub ends. The weld zone on the catalyst tube was heat treated at 980°C prior to welding and again after completion of the welding. The part replaced tubes are in service for over ten months.

CONCLUSION

The repeated stress corrosion failures experienced at the inlet material portions of the reformer tubes in MFL Ammonia plant and the extent and severity of such cracking are unusual in the history of reformer operating plants in and outside India. Considerable experience has been gained from these failures and the subsequent metallurgical studies. High residual weld stress at the stub end weld region was identified as primarily responsible for the stress cracking. Repeated repairs accelerated the time-to-failure rate. Heat treatment of the stub and weld zones to mill-anneal temperature (980°C) is practical and would considerably bring down the residual stresses. The residual stresses will be less than 20% of the yield stress. This appears to be an effective method of reducing the incidence of stress corrosion failures in future.

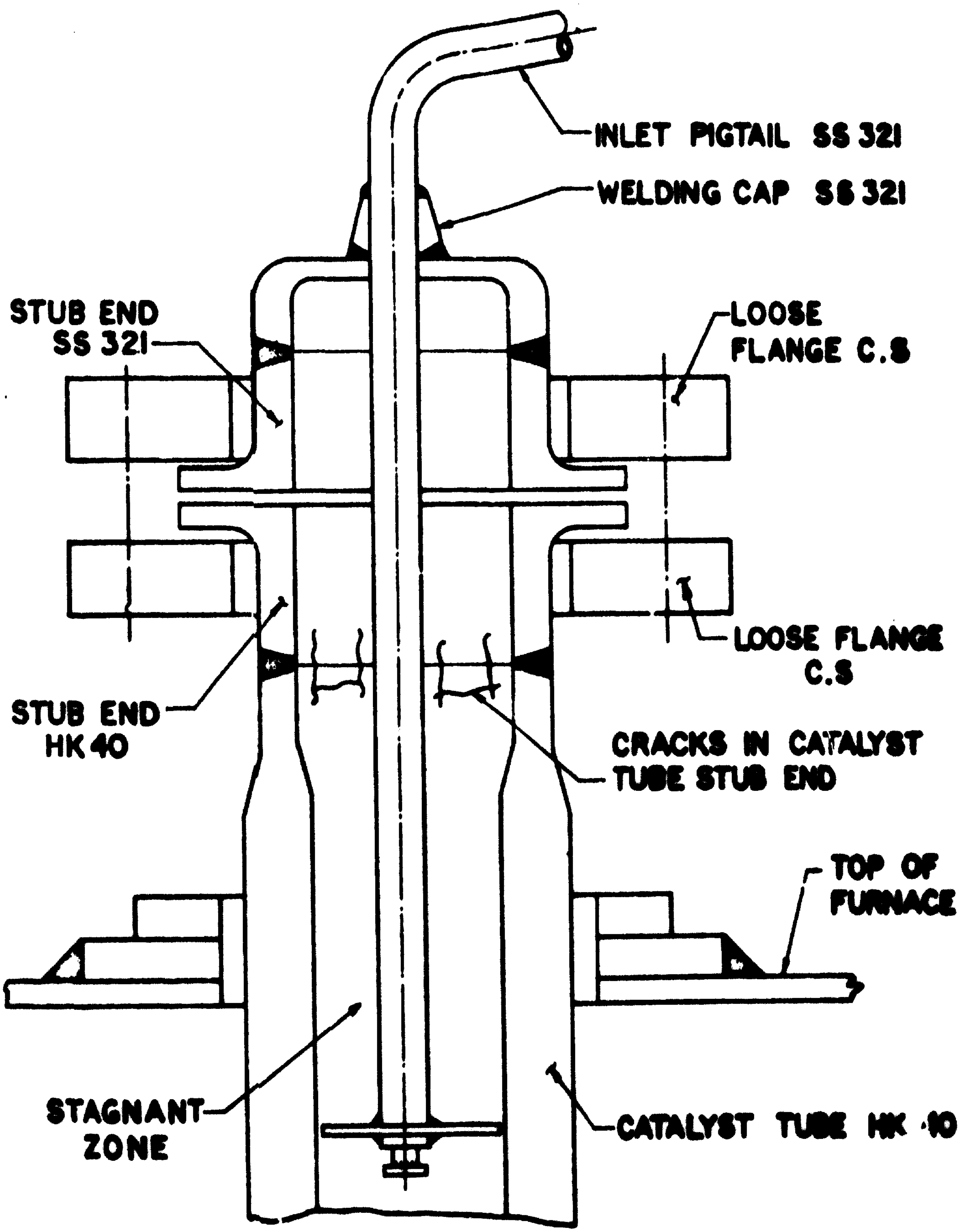


FIG. 1. CATALYST TUBE STUB END

Fig 2(a)

Tangential section near the ID surface, showing transgranular cracks in the HAZ adjacent to the weld at the stub end (HK 40).

X 400

Fig 2(b)

Tangential section near the ID surface of the stub end. Cracks predominantly intergranular.

X 200

Attachment 2

Figure 3 (a)
Intergranular cracking in sensitized Inconel-alloy 600
Etchant : Glyceragia + Acetic Acid 500x

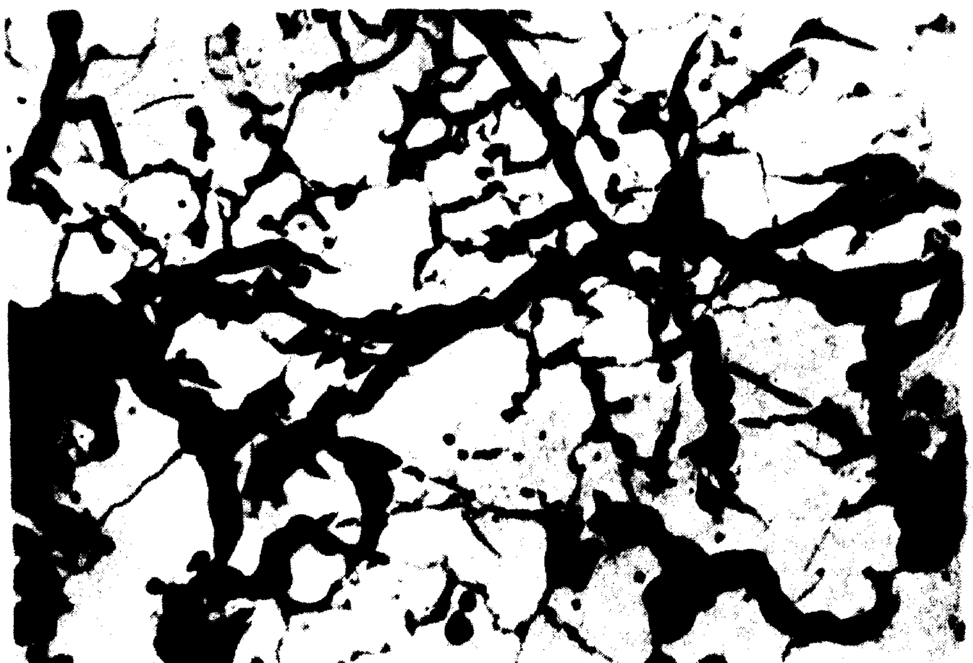


Figure 3(b)
Intergranular and transgranular cracking in SK 40 catalyst tube.
Photo of longitudinal cracks. Etchant:Glyceragia+Acetic Acid.
500x

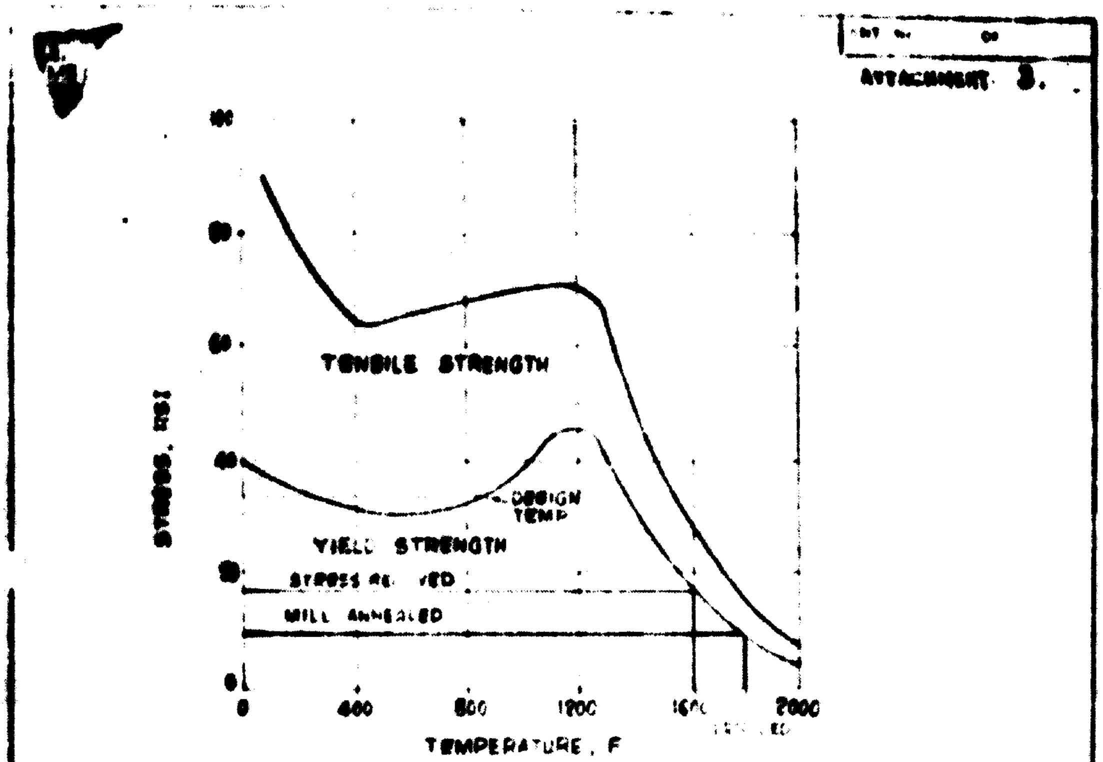
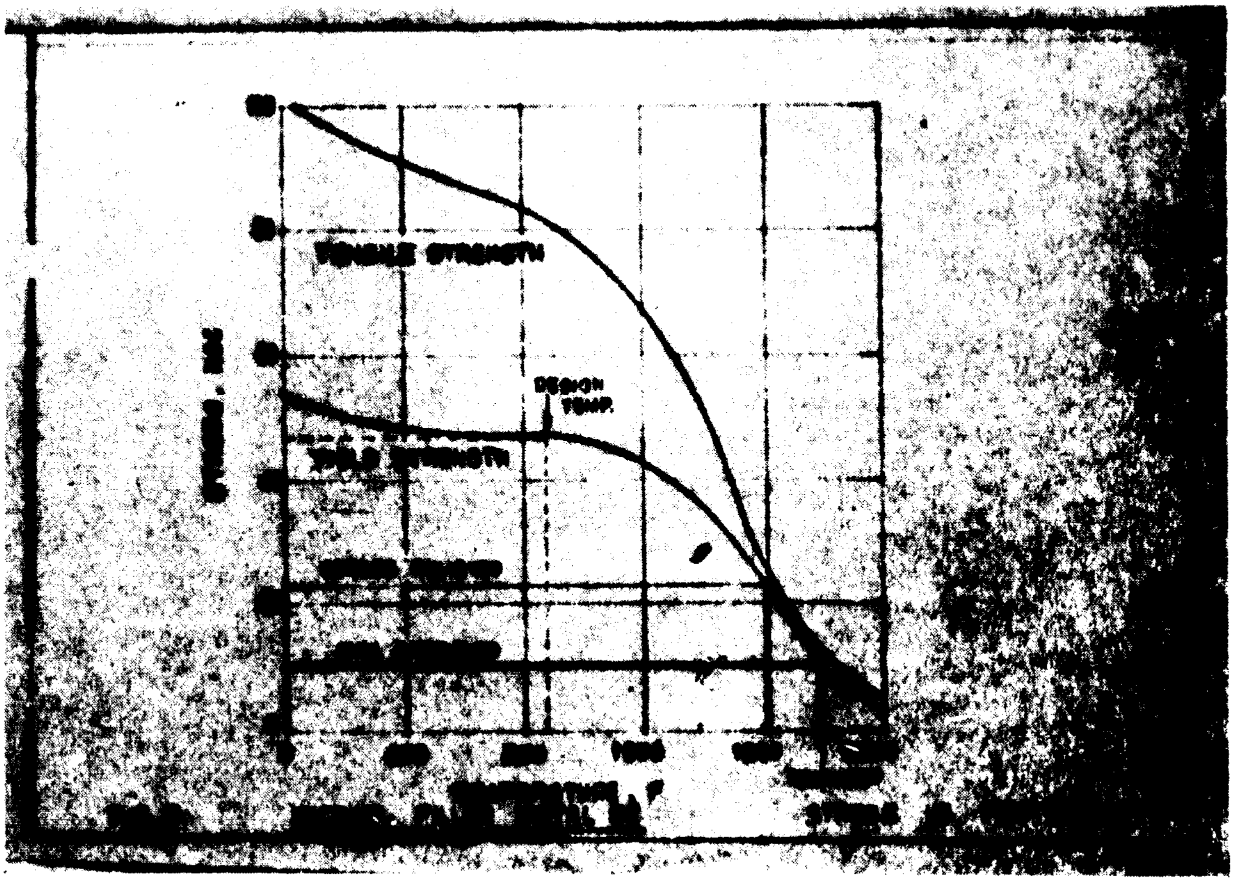


FIG 4. CENTRIFUGALLY CAST HK-40 STRESS VS TEMP CURVE



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