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REPORT

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INFLUENCE OF HNS ON THE MICROSTRUCTURE AND PROPERTIES OF CAST TNT

M.A. Parry and B.W. Thorpe

Approved for Public Release

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ABSTRACT

The influence of the additive 2,2',4,4',6,6'-hexanitrostilbene (HNS) on the physical properties of cast 2,4,6-trinitrotoluene (TNT) has been studied. As little as 0.3% HNS incorporated by the cycle-cast technique effects exceptional grain modification of the TNT, with an associated fourfold increase in strength. The same grain modification and increase in mechanical strength were achieved by the addition of pre-produced $(TNT)_2^3HNS$ complex to TNT at 90°C, and was unaffected by holding at that temperature for up to 4 h before casting. The simple inclusion of HNS caused a minor modification of the grain structure of TNT castings and a smaller increase in their mechanical strengths. These results are consistent with the inferior nucleation efficiency of HNS compared with the $(TNT)_2^3HNS$ complex.

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The influence of the additive 2,2',4,4',6,6'-hexanitrostilbene (HNS) on the physical properties of cast 2,4,6-trinitrotoluene (TNT) has been studied. As little as 0.3% HNS incorporated by the cycle-cast technique effects exceptional grain modification of the TNT, with an associated fourfold increase in strength. The same grain modification and increase in mechanical strength were achieved by the addition of pre-produced $(TNT)_2HNS$ complex to TNT at 90°C, and was unaffected by holding at that temperature for up to 4 h before casting. The simple inclusion of HNS caused a minor modification of the grain structure of TNT castings and a smaller increase in their mechanical strengths. These results are consistent with the inferior nucleation efficiency of HNS compared with the $(TNT)_2HNS$ complex.

CONTENTS

INFLUENCE OF HNS ON THE MICROSTRUCTURE AND PROPERTIES OF CAST TNT

1. INTRODUCTION

Many Australian munitions are filled with melt-cast TNT-based explosives such as Composition B (RDX/TNT/Beeswax 60/40/1). TNT solidifies from the melt as large, highly oriented, columnar grains. This TNT matrix contracts by about 12% on solidification, and the further contraction during cooling of the solid cast (significantly greater than that of steel) can cause serious cracking and air-gaps unless special precautions are taken. Furthermore, TNT is an intrinsically weak, brittle material and it is therefore difficult to produce high quality casts from TNT-based compositions. Casting defects such as base-gaps, cracks and voids have been held responsible for premature initiation of explosive-filled projectiles in response to set-back forces during gun-firing.

Over the last 30 years there have been many investigations of TNT and TNT-based explosives aimed at improving filling quality. Two approaches have been used; first, to increase strength, second to make the material more 'compliant', that is to add plasticisers or at least to lower the elastic modulus. For example, terylene fibres were incorporated as filaments to increase tensile strength. Plasticisers have been used to reduce the incidence of cracking; for example, α-nitronaphthalene, 1,2-dihydroxybenzene (catechol) and 2,4,6-trinitroanisole were added to laboratory castings of TNT. It appeared that 0.2-0.4% α-nitronaphthalene was a most effective additive in reducing cracks which appeared at the surface of the castings [1]. However, radiography showed no discernible difference in the extent of cracking when these additives were included in either TNT or Composition B filled M107 155 mm shell, whilst the extent of exudation [2] was clearly increased. Experiments [3,4] have also investigated the effects of the following additives on the mechanical properties of Composition B: o-/p-nitrotoluene mixtures, alkyd resins, Span 80A, sorbitan monostearate, sorbitan monooleate, pyrogallic acid, cyclohexanone, anthracene, naphthalene and tetryl. It was found that improvement in the quality of production

fillings correlated with a reduction in the elastic modulus of the experimental cast. More recently, attempts have been made to reduce cracking and exudation simultaneously by adding mixtures of additives to a number of other TNT-based compositions [5].

An alternative approach has been to include the heat resistant explosive 2,2',4,4',6,6'-hexanitrostilbene (HNS), which has been shown to be an effective additive for the grain modification of the TNT-matrix (6-10), preventing the growth of the large columnar grains with preferred orientation. For most efficient use of the additive as a grain modifier, a cycle-cast method has been used [6], in which a small concentration of HNS in TNT is heated to 100°C, the solution is stirred and allowed to resolidify; the mixture is then remelted with the constraint that the melt temperature not exceed 85°C. Resolidification then produces an isotropic cast of extremely fine, randomly oriented grains. Recent work [8-10] in these laboratories has elucidated the mechanism by which the cycle-cast process operates, and has identified the nucleating species as the molecular complex $(TNT)_2HNS$. This complex has been prepared, isolated and characterised by differential scanning calorimetry. This paper reports a study of the physical properties (density, TNT grain size and orientation, and mechanical strength) of TNT casts containing up to 4.8% HNS incorporated by several methods aimed at optimising the HNS concentration and the casting procedure. The effect of HNS on the more complex TNT-based compositions such as Composition B will be reported in a later paper.

2. EXPERIMENTAL

Experiments were designed to assess the effect of the addition of small concentrations of HNS on the properties of TNT-HNS casts. Casts were prepared by;

(a) thermal cycling of the TNT-HNS mixture prior to pour (the cycle-cast procedure) [6],

(b) allowing partial solidification of TNT before pouring ("poured-cloudy"),

(c) simple addition of the pre-produced $(TNT)_2HNS$ complex, [9] and

(d) simple addition of HNS.

2.1 Materials

Commercial grade TNT with a purity of 99.7% was used as supplied by Albion Explosives Factory (AEF).

HNS was prepared by Explosives Factory Maribyrnong (EFM) according to the general method of Shipp [11]. Thin layer chromatography showed that this

material contained up to 5% of 2,2',4,4',6,6'-hexanitrobibenzyl (HNB), formed as a reaction byproduct. Since HNB is not a nucleant for TNT [7] and is therefore expected to have little effect in this work, the commerical HNS as supplied by EPM was used in the casts.

Pre-produced complex $(TNT)_2HNS$ was prepared from HNS and TNT of commercial purity by techniques described previously, and enriched by filtration from the molten TNT [9].

2.2 Casting Procedure

The four series of casts summarised in Table 1 were prepared according to the following procedure.

(a) *Thermal cycling of TNT and the TNT-HNS mixture*

TNT containing 0, 0.3, 0.6, 0.9, 1.2, 1.8, 2.4, 3.6 and 4.8% by weight of added HNS were used. The lowest concentration of 0.3% HNS was selected to ensure the presence of solid HNS, since HNS is soluble in TNT to the extent of 0.2% at 85°C [6]. All formulations were pressure cast in a 63 mm diameter mould according to the following procedure, which includes the essential features described in the patented cycle-cast method [6].

1. TNT was heated to 100°C, and the calculated weight of HNS was added slowly and stirred for one hour.

2. The mixture was cooled until completely solidified.

3. The mixture was remelted and heated to 85°C, and then poured. (To ensure that the reheat temperature did not exceed 85°C, a thermostat-controlled heater was used). For each cast the remelt time was 2.25-2.5 hours.

4. During the remelt stage the mould was maintained at 85°C. After pouring, the lower half of the mould was adjusted to 50°C, whilst the upper half of the mould remained at 85°C. In this experimental arrangement solidification in the lower half of mould was promoted whilst the upper half of the mould acted as an effective "header", a reservoir of molten mixture to offset the volume change during solidification.

5. Immediately after pour, an air pressure of 350 kPa (50 psi) was applied to the mould and maintained until solidification was complete. After a two hour period the mould was allowed to cool to ambient.

(b) *"Poured-cloudy" TNT*

"Poured-cloudy" TNT casts were prepared for purposes of comparison by an adaptation of the procedure in (a). The remelt mixture (which contained no HNS) was cooled to about 80°C with stirring until a slurry of fine crystalline TNT developed in the liquid, and the resultant slurry was cast as in (a).

(c) *Addition of pre-produced complex $(TNT)_2HNS$*

TNT was heated to 90°C and about 1% pre-produced complex $(TNT)_2HNS$ was added; the mixture was then stirred for 5 minutes, 1 hour or 4 hours prior to pour. The solidification procedure described in (a) was followed, with the exception that the explosive was open cast i.e. cast without the application of air pressure.

(d) *Simple addition of HNS*

(i) TNT was heated to 85°C and 0.9% HNS was added and stirred for 5 minutes prior to pour.

(ii) TNT was heated to 100°C and 0.9% HNS was added and stirred for 1 hour prior to pour.

The solidification procedure followed was that described in (a).

2.3 Explosives Machining

The casts were sectioned radially by remote controlled band sawing to remove the header, and then sectioned longitudinally to leave two equal semicylindrical sections from the lower half of the mould. For each formulation one such semicylindrical section was polished [12] and photographed, and sectioned for measurement of density and TNT grain size and orientation as illustrated in Figure 1. The remaining semicylindrical section(s) were machined into cylinders 50.8 mm long and 20.3 mm in diameter for mechanical testing; the axes of these cylinders being parallel to the axis of the cast.

2.4 Measurement of Density

Sections B, D and F were machined into four pieces as shown in Figure 1. Since cast TNT is porous, pieces from all casts were coated with a thin film of paraffin wax by immersing briefly in a 2% solution of wax in petroleum ether (40-60°C) and allowing the solvent to evaporate. Their densities were then measured by the water displacement technique.

2.5 *Examination of TNT Microstructure*

Sections A, C, E and G were polished [12] and etched with bromoform. The grain size and orientation were examined throughout the casts using a Leitz Ortholux microscope with reflected light.

2.6 *Mechanical Testing*

Machined cylinders were tested under uniaxial compression at 18-20°C using an Instron Universal Testing Machine fitted with a combination tension-compression load cell DRM (Metric). The strain rate was 0.04 min^{-1} for all tests. The ultimate compressive strength was measured, and values for Young's modulus were calculated from the linear portion of the test curve.

3. RESULTS AND DISCUSSION

3.1 *Grain Structure*

(a) *TNT, TNT-HNS and 'poured-cloudy' TNT casts produced by the cycle-cast technique*

TNT without added HNS, cast under the experimental conditions detailed in 2.2 (a), is shown in Figure 2. As has been shown previously [13], solidification of TNT at 50°C produces a chilled layer containing the characteristic spherulitic structure shown in Figure 2 (b), while the bulk of the material consists of large radially aligned TNT grains as shown in Figure 2 (a). The TNT grains of the cast vary in size with the largest being several centimetres long and almost a centimetre wide. Photomicrographs of the cast are shown in Figures 3 (a) and 3 (b) for the chilled layer and large grained zone respectively. The randomly oriented grains in the chilled layer are less than 1 mm long and in the bulk of the cast the grain boundaries are aligned almost radially.

The highly oriented large grained structure of TNT was changed dramatically by the incorporation of as little as 0.3% of HNS using the cycle-cast technique. The modified grain structure in shown in Figure 4. The spherulitic chilled zone does not occur since the presence of the highly active nucleating species prevents the undercooling required for its production. More significantly, the grain size is greatly reduced and the preferred radial orientation disappears. Photomicrographs of the cast are shown in Figures 5 (a) and 5 (b). The largest TNT grains are about 1 mm long. Once again, the TNT grains in the chilled layer are smaller than in the bulk of the casting. The TNT grains are not truly equiaxed, but retain much of their elongated habit. (The 0.3% HNS/TNT cast is similar in appearance to the "poured-cloudy" cast shown in Figures 5 (c) and 6, and both would be expected to exhibit isotropic mechanical and physical properties). This grain refinement indicates that sufficient constitutional undercooling [14] occurs ahead of the growth front to allow activation of the nucleation sites provided

by the presence of the $(TNT)_2HNS$ complex. Because of the potency of the complex as a nucleant only a degree or two of constitutional undercooling is necessary for extensive grain refinement.

No further change was observed in the appearance of the TNT-HNS casts when the concentration of HNS was increased to 1.2%. In particular, inspection of the TNT microstructure showed that the apparent size, orientation and shape of the grains were similar to those of the 0.3% HNS/TNT cast. When the HNS concentration increased above 1.2%, however the TNT grain size also increased, although the random grain orientation was apparently retained. Figure 7 shows the sectioned 4.8% HNS/TNT cast and Figure 5 (d) is a photomicrograph of the 3.6% HNS/TNT cast.

(b) *TNT-HNS casts produced by the addition of the $(TNT)_2HNS$ complex*

Three casts were prepared by the addition of about 1% of pre-produced $(TNT)_2HNS$ to TNT at 90°C, and stirring at that temperature for 5 minutes, 1 hour and 4 hours respectively. The exceptional efficiency of this species as a grain modifier for the TNT system had previously been demonstrated, and the three experimental castings in this series showed once again the random array of small grains and the absence of a spherulitic chilled layer. The grain structure illustrated in Figure 8 was similar to the grain structure of the cycle-cast TNT-HNS formulations. It therefore appears that a TNT melt temperature of 90°C does not seriously degrade the efficiency of the nucleant. A more comprehensive examination of the isothermal stability of the $(TNT)_2HNS$ complex is in progress.

(c) *TNT-HNS casts produced by simple addition of HNS*

Casts were prepared in which 0.9% HNS was added to TNT at 85°C and poured immediately, and in which the HNS was added to the TNT at 100°C and held at that temperature for an hour before pouring. Each casting had a grain structure intermediate between that of TNT without HNS and that of the fine-grained material prepared by either the cycle-cast technique or the direct addition of the $(TNT)_2HNS$ complex. The chilled layer region had many more nucleation sites that the characteristic spherulite region of TNT with HNS, but not as many as the cycle-cast material. On the other hand the bulk of the cast is composed of large columnar grains, although they are not as well oriented as those in TNT without HNS, and the central "core" is not well defined. These results are consistent with previous observations [8] that HNS itself is a nucleant for TNT crystal growth, but it is much inferior to the efficient $(TNT)_2HNS$ complex. Figure 9 shows an example of the grain structure of a cast produced after stirring for 1 hour at 100°C.

3.2 Density Measurement

The density of "poured-cloudy" TNT, TNT without HNS and TNT-HNS formulations (to 4.8% HNS) prepared by the cycle-cast technique are given in Table 2. Not surprisingly, since the density of TNT without HNS is about 1.62

Mg/m^3, 98% of the crystal density 1.654 Mg/m^3, there is very little variation in density. There appears to be a slightly lower density at the central core and, when the higher density of HNS (1.74 Mg/m^3) is taken into account, there is only a slight decrease in voidage with increasing HNS. In view of the minimal changes found in the cycle-cast formulations, the densities of formulations prepared by simple addition of the $(TNT)_2HNS$ complex or HNS itself were not measured.

3.3 Mechanical Testing

(a) *TNT, TNT-HNS and "poured-cloudy" TNT casts produced by the cycle-cast technique*

The ultimate compressive strength of TNT without HNS, "poured-cloudy" TNT and compositions of up to 4.8% HNS in TNT prepared by the cycle-cast procedure are given in Table 3. As previous work has shown [15], the compressive strength will vary within a cast depending on the position from which the specimen was taken, and results from casts with only a few specimens should be treated with caution, in case they are unrepresentative. However, in casts from which 16 specimens were tested, the standard deviations and ranges of strengths were similar for TNT-HNS and TNT. The ultimate compressive strength of TNT without HNS is only about 3 MPa, but this may be increased to about 10 MPa by pouring cloudy. Alternatively the ultimate compressive strength may be increased to 11-12 MPa by the addition of 0.3-4.8% HNS by the cycle-cast process. However, there appears to be little gain in strength on increasing the concentration of HNS above about 0.3%. Thus the modification of the TNT grain structure to fine, randomly-oriented grains by the addition of HNS by the cycle-cast process is accompanied by a substantial increase in mechanical strength.

Typical compression test stress-strain curves for TNT without HNS and for cycle-cast TNT-HNS containing 0.3% and 4.8% HNS are included in Figure 10, and show a pronounced but variable departure from linearity at low stress levels. This non-linearity is attributed to a combination of machine "slack" and geometric asymmetry in the specimens, and was subtracted to obtain genuine material response.

The stress-strain curves were found to be linear up to about 90% of the ultimate stress. Values of Young's modulus were obtained from the gradient of the linear portion of the stress-strain curves and are presented in Table 4. A twofold increase in Young's modulus is obtained by the addition of HNS to TNT, although there is significant variation both between specimens of the same cast and between specimens of different casts. An increase in Young's modulus is undesirable as it has been shown to be correlated with the incidence of cracking [3]. Nonetheless a twofold increase in Young's modulus associated with a fourfold increase in ultimate compressive strength yields an approximate twofold increase in strain to failure and should improve the resistance to fracture in these materials.

The results described above are for pressure-cast explosives. Without application of pressure, TNT has a lower ultimate compressive strength

(2 MPa), but the addition of HNS by the cycle-cast technique still achieves a fourfold increase in strength.

(b) *TNT-HNS casts produced by the addition of the $(TNT)_2HNS$ complex*

Ultimate compressive strength and Young's modulus for TNT casts prepared by the addition of pre-produced $(TNT)_2HNS$ complex are presented in Table 5. Given that these compositions were open cast (i.e. no pressure was applied during solidification) the mechanical strength and Young's modulus of the materials were comparable with those prepared by the cycle-cast method. Furthermore, heating at 90°C for 4 hours prior to casting had no deleterious effect on the mechanical properties. It is therefore possible to prepare TNT castings with modified grain structure and increased mechanical strength by simple addition of pre-produced $(TNT)_2HNS$ complex and without restricting the final melt temperature to 85°C as is required by the patented cycle-cast process.

(c) *TNT-HNS casts produced by simple addition of HNS*

The ultimate compressive strength and Young's modulus for TNT casts prepared by the simple addition of HNS are given in Table 6. The mechanical strength and Young's modulus of these casts are intermediate between those of TNT without HNS and TNT modified by the inclusion of HNS by the cycle-cast technique or by the addition of the $(TNT)_2HNS$ complex. These results parallel observations of the microstructure of these casts, and are consistent with the known slight nucleating ability of HNS itself, albeit very much inferior to the $(TNT)_2HNS$ complex, the active nucleant in the cycle-cast process. It was also observed that the mechanical strength of the cast was increased by holding the mixture at a higher temperature for an hour before pouring, although not to the full strength of the fine-grained material. This could be taken as evidence for slow formation of the complex even without the cooling and reheating cycle.

4. SUMMARY

The optimum concentration of HNS required for the improvement of TNT physical properties is very low. The preparation of TNT casts by the cycle-cast process requires only 0.3% HNS to modify the grain structure and provide the associated increase in strength. A fine-grained cast with no evidence of preferred orientation is produced, with a slight increase in density and a fourfold increase in compressive strength. There appears to be no advantage in using more than 0.3% HNS.

Casts of similar quality are produced by the addition of pre-produced $(TNT)_2HNS$ to TNT at 90°C. This method allows some alleviation of the 85°C constraint on the remelt temperature of the cycle-cast technique.

The grain structure and mechanical properties of casts prepared by the

simple addition of HNS to TNT reflect the inferior nucleating efficiency of HNS compared with the $(TNT)_2HNS$ complex.

TNT forms the supporting matrix of such castable explosive formulations as Composition B, and the effect of HNS on the grain structure and mechanical properties of such mixtures should therefore be evaluated.

5. ACKNOWLEDGEMENTS

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TABLE 1

SUMMARY OF CASTING PROGRAMME

Series	Type	No. of Casts
(a)	TNT with 0 to 4.8% HNS, cycle cast and solidified under pressure;	23
(b)	TNT "poured-cloudy" and solidified under pressure;	3
(c)	TNT with about 1% of pre-produced complex $(TNT)_2HNS$ added at 90°C and solidified without pressure (open cast).	3
(d)	TNT with 0.9% HNS simply added at 85°C and 100°C and solidified under pressure.	4

TABLE 2

DENSITY OF TNT, "POURED-CLOUDY" TNT AND TNT-HNS CASTS

(Refer Figure 1)

Cast %HNS	Part	Piece Number				Density Mg/m^3	
		1	2	3	4	Part mean	Cast mean (S.D.)
0 TNT	F	1.620	1.625	1.623	1.615	1.621	
	D	1.624	1.622	1.622	1.614	1.621	1.620
	B	1.620	1.620	1.624	1.613	1.619	(0.004)
					1.614		
0 TNT	F	1.617	1.617	1.619	1.611	1.616	
	D	1.618	1.617	1.620	1.609	1.616	1.616
	B	1.619	1.617	1.619	1.612	1.617	(0.004)
					1.611		
0 TNT "poured-cloudy"	F	1.620	1.620	1.621	1.620	1.620	
	D	1.623	1.621	1.622	1.620	1.622	1.621
	B	1.622	1.621	1.622	1.620	1.621	(0.001)
					1.620		
0 TNT "poured-cloudy"	F	1.618	1.616	1.618	1.619	1.618	
	D	1.618	1.617	1.617	1.620	1.618	1.618
	B	1.618	1.620	1.618	1.621	1.619	(0.001)
					1.620		
0.3	F	1.624	1.627	1.626	1.623	1.625	
	D	1.623	1.626	1.624	1.624	1.624	1.625
	B	1.624	1.624	1.626	1.624	1.625	(0.001)
					1.624		
0.6	F	1.621	1.623	1.624	1.620	1.622	
	D	1.623	1.623	1.625	1.621	1.623	1.622
	B	1.623	1.615	1.625	1.623	1.622	(0.003)
					1.621		

TABLE 2
(Continued)

Cast %HNS	Part	Piece Number				Density Mg/m^3	
		1	2	3	4	Part mean	Cast mean (S.D.)
0.9	F	1.623	1.621	1.623	1.616	1.621	
	D	1.621	1.619	1.623	1.618	1.620	1.621
	B	1.624	1.622	1.624	1.619	1.622	(0.003)
					1.618		
1.2	F	1.622	1.619	1.625	1.619	1.621	
	D	1.620	1.617	1.623	1.618	1.620	1.620
	B	1.619	1.618	1.623	1.618	1.620	(0.003)
					1.618		
1.8	F	1.622	1.624	1.624	1.619	1.622	
	D	1.622	1.622	1.623	1.618	1.621	1.622
	B	1.623	1.625	1.624	1.619	1.623	(0.002)
					1.619		
2.4	F	1.623	1.624	1.624	1.619	1.623	
	D	1.622	1.623	1.625	1.620	1.623	1.623
	B	1.625	1.623	1.623	1.620	1.623	(0.002)
					1.620		
3.6	F	1.626	1.625	1.627	1.622	1.625	
	D	1.626	1.626	1.627	1.622	1.625	1.625
	B	1.625	1.625	1.626	1.622	1.625	(0.002)
					1.622		
4.8	F	1.626	1.627	1.629	1.625	1.627	
	D	1.627	1.629	1.629	1.624	1.627	1.627
	B	1.627	1.627	1.627	1.623	1.626	(0.002)
					1.624		

TABLE 3

COMPRESSIVE STRENGTH OF TNT, "POURED-CLOUDY" TNT AND TNT-HNS CASTS

Casting Details			Ultimate Compressive Strength (MPa)			Density
% HNS added	No. Casts	No. Specimens	Mean	S.D.	Range	Mg/m^3
0 TNT	5	8 4 3 16 6	3.1 2.8 3.0 3.7 3.1	0.5 0.3 0.3 0.6 0.3	0.4 0.7 0.5 1.7 0.7	 1.620 1.616
0 TNT "poured-cloudy"	3	8 7 8	9.4 9.9 11.3	0.7 0.9 0.3	1.3 2.1 0.8	 1.621 1.618
0.3	2	5 16	11.1 12.9	0.6 0.7	1.7 2.4	1.625
0.6	2	6 16	11.7 11.3	1.0 0.7	2.7 2.7	1.622
0.9	2	7 16	12.0 12.5	0.5 0.6	1.6 2.1	1.621
1.2	2	7 15	12.2 12.6	0.4 0.7	1.1 2.3	1.620
1.8	3	8 16 8	10.9 12.0 10.9	0.5 0.6 0.2	1.4 1.6 0.5	 1.622

TABLE 3

(Continued)

Casting Details			Ultimate Compressive Strength (MPa)			Density
% HNS added	No. Casts	No. Specimens	Mean	S.D.	Range	Mg/m^3
2.4	3	8 16 8	10.0 11.8 11.4	0.4 0.5 0.3	0.7 1.5 0.6	1.623
3.6	2	16 8	12.3 10.4	0.4 0.3	1.4 0.9	1.625
4.8	2	16 7	13.3 11.6	0.5 0.2	1.5 0.5	1.627

TABLE 4

ESTIMATES OF YOUNG'S MODULUS FROM COMPRESSION TESTS

Cast		Young's Modulus (MPa)		UCS of Cast (MPa)	
HNS added (%)	No. Specimens	Mean	S.D.	Mean	S.D.
0 TNT	16 6	1140 1260	110 120	3.7 3.1	0.6 0.3
0 TNT "poured-cloudy"	8	2100	100	11.3	0.3
0.3	16	2130	140	12.9	0.7
0.6	16	1980	100	11.3	0.7
0.9	15	2210	80	12.5	0.6
1.2	16	2220	80	12.6	0.7
1.8	16 8	2210 2500	80 170	12.0 10.9	0.6 0.2
2.4	16 8	2190 2500	60 190	11.8 11.4	0.5 0.3
3.6	16 8	2320 2410	60 180	12.3 10.4	0.4 0.3
4.8	16 7	2380 2300	120 90	13.3 11.6	0.5 0.2

TABLE 5

MECHANICAL PROPERTIES OF TNT-HNS CASTS

PRODUCED BY THE ADDITION OF $(TNT)_2HNS$ COMPLEX

Pre-pour Heat Time (at 90°C)	No. Casts	No. Specimens	Ultimate Compressive Strength (MPa)		Young's Modulus (MPa)	
			Mean	S.D.	Mean	S.D.
5 minutes	1	8	10.7	0.6	2010	100
1 hour	1	8	11.2	0.5	2070	40
4 hours	1	8	10.6	0.6	2040	80

TABLE 6

MECHANICAL PROPERTIES OF TNT-HNS CASTS PRODUCED BY SIMPLE ADDITION OF HNS

Pre-pour Conditions	No. Casts	No. Specimens	Ultimate Compressive Strength (MPa)		Young's Modulus (MPa)	
			Mean	S.D.	Mean	S.D.
85°C (5 min)	2	8	4.8	0.4	1460	65
		7	4.7	0.8	1480	120
100°C (1 hour)	2	8	7.0	1.0	1840	250
		8	6.8	0.9	1910	110

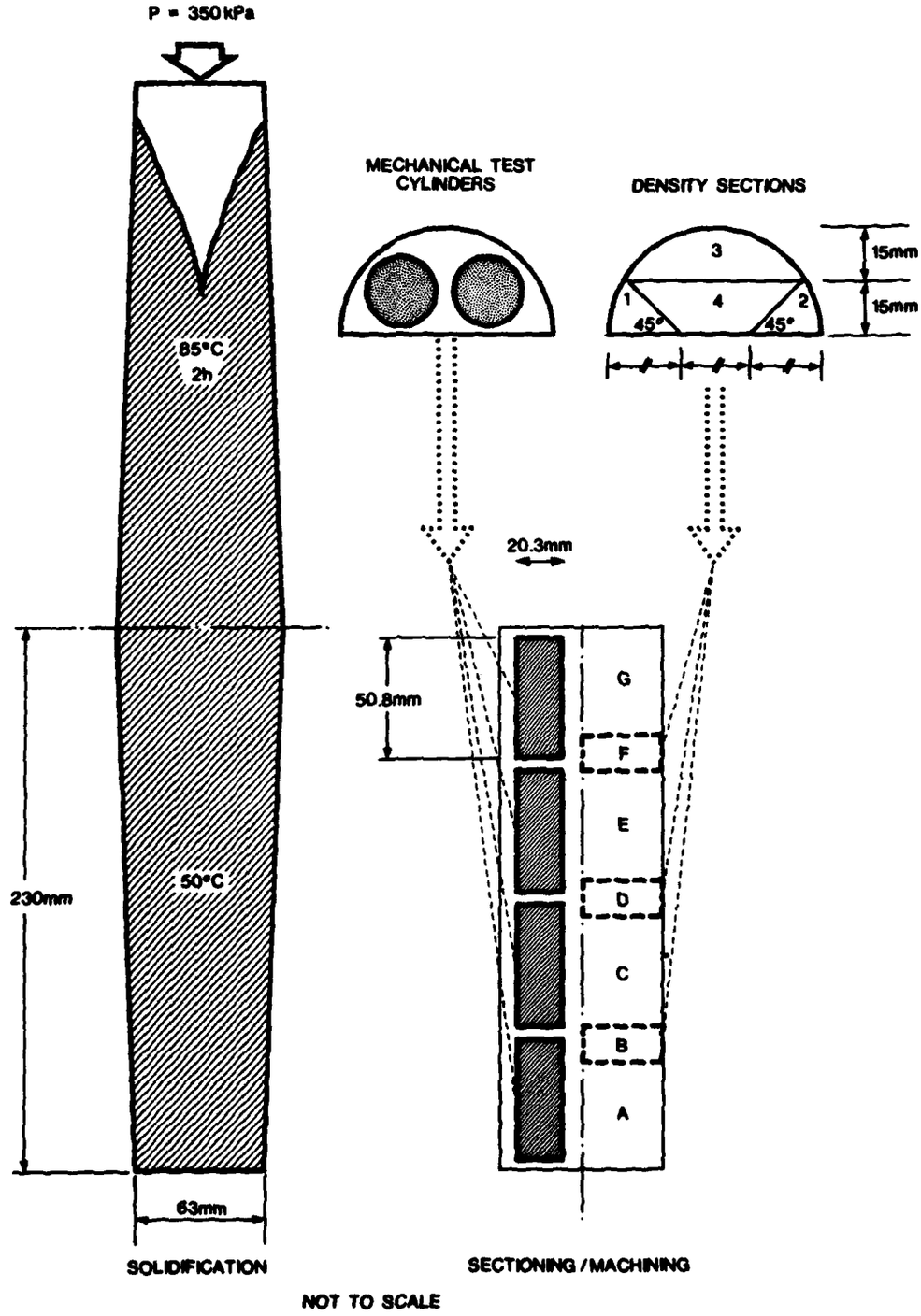
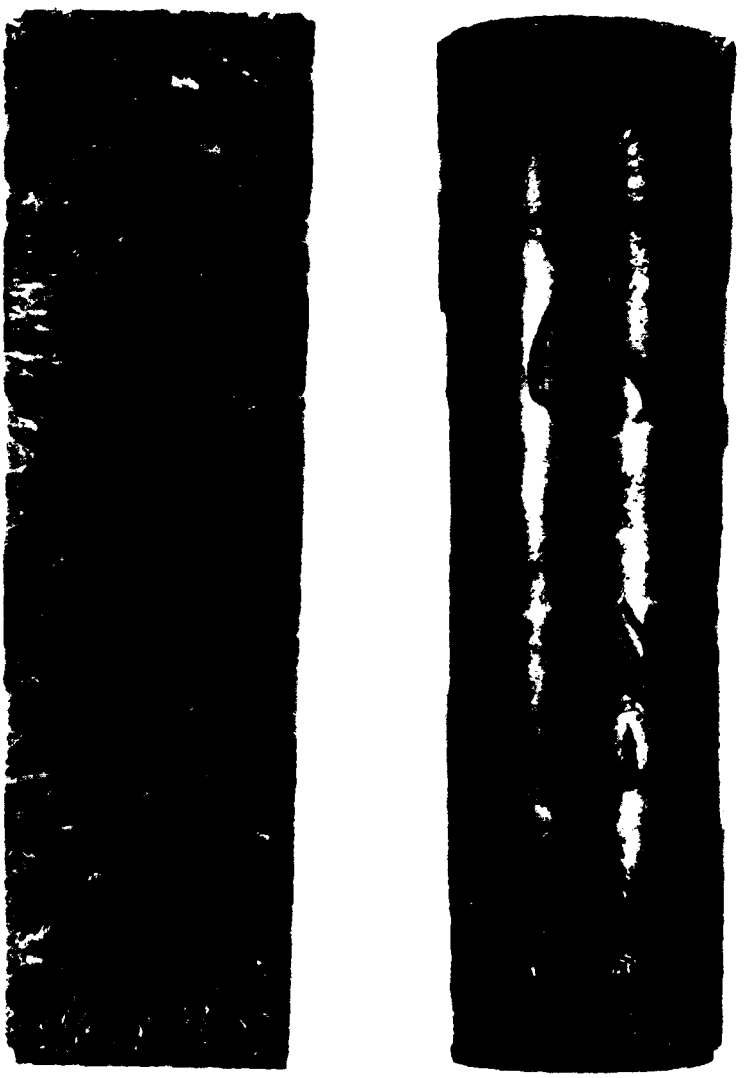
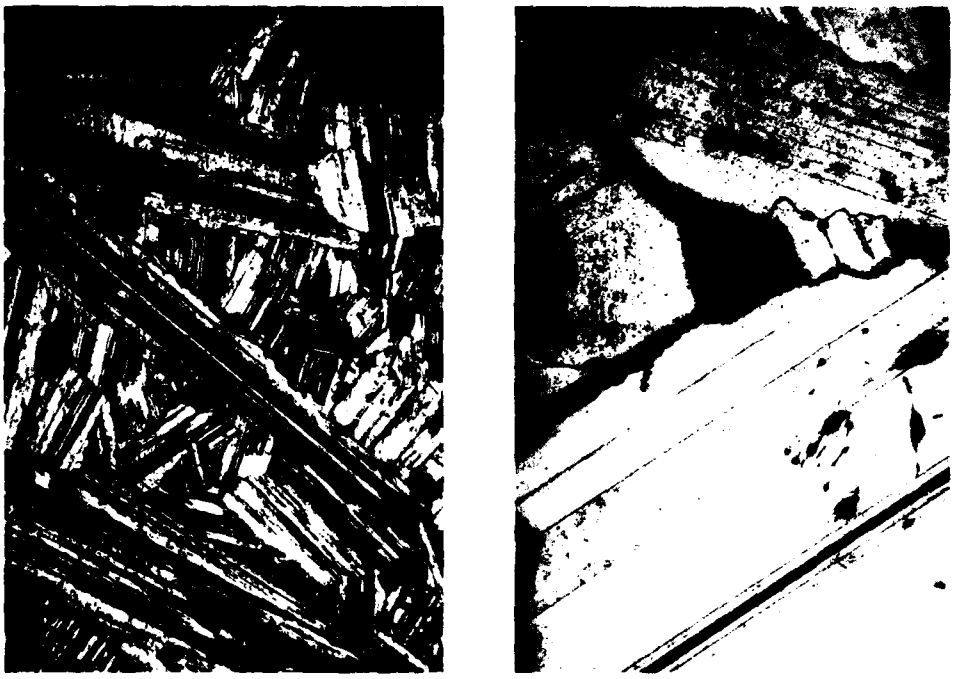


FIG. 1 - Explosives Machining Geometry



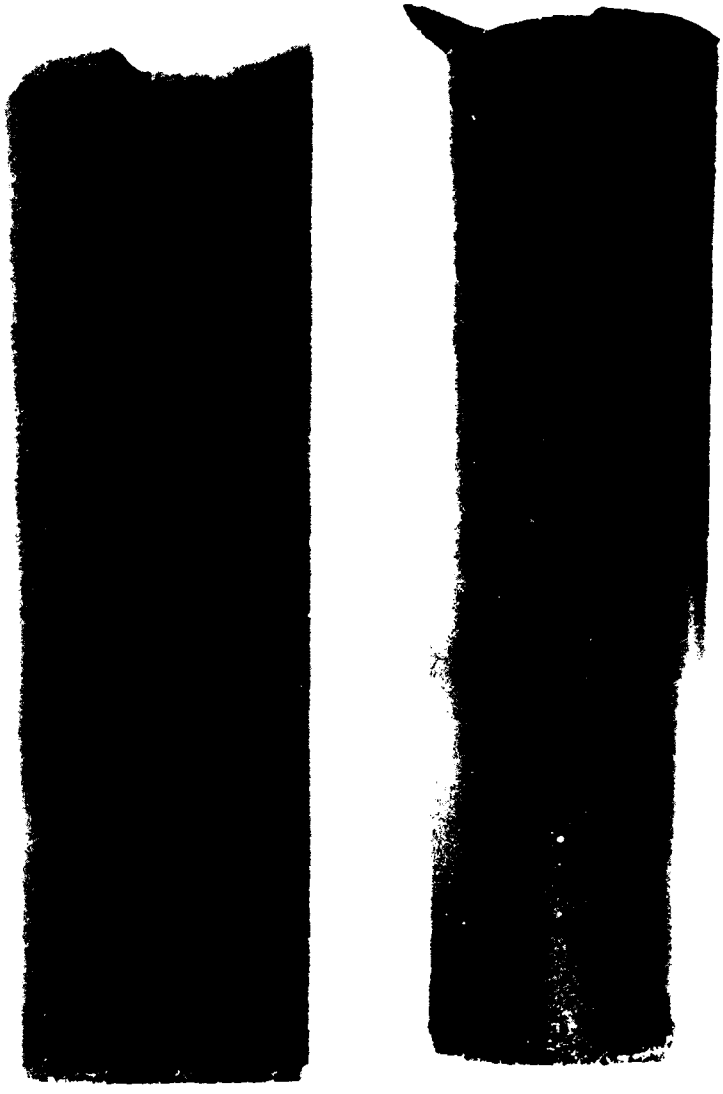
(a) (b)

FIG. 2 - TNT cast without HNS
(a) Large-grained zone in bulk
(b) Spherulite chilled layer surface



(a) (b)

FIG. 3 - Photomicrographs of polished specimen of TNT cast without HNS
(a) Chilled layer
(b) Large-grained zone



(a) (b)

FIG. 4 - TNT-HNS cycle-cast with 0.3% HNS
(a) Fine-grained zone in bulk
(b) Chilled layer surface

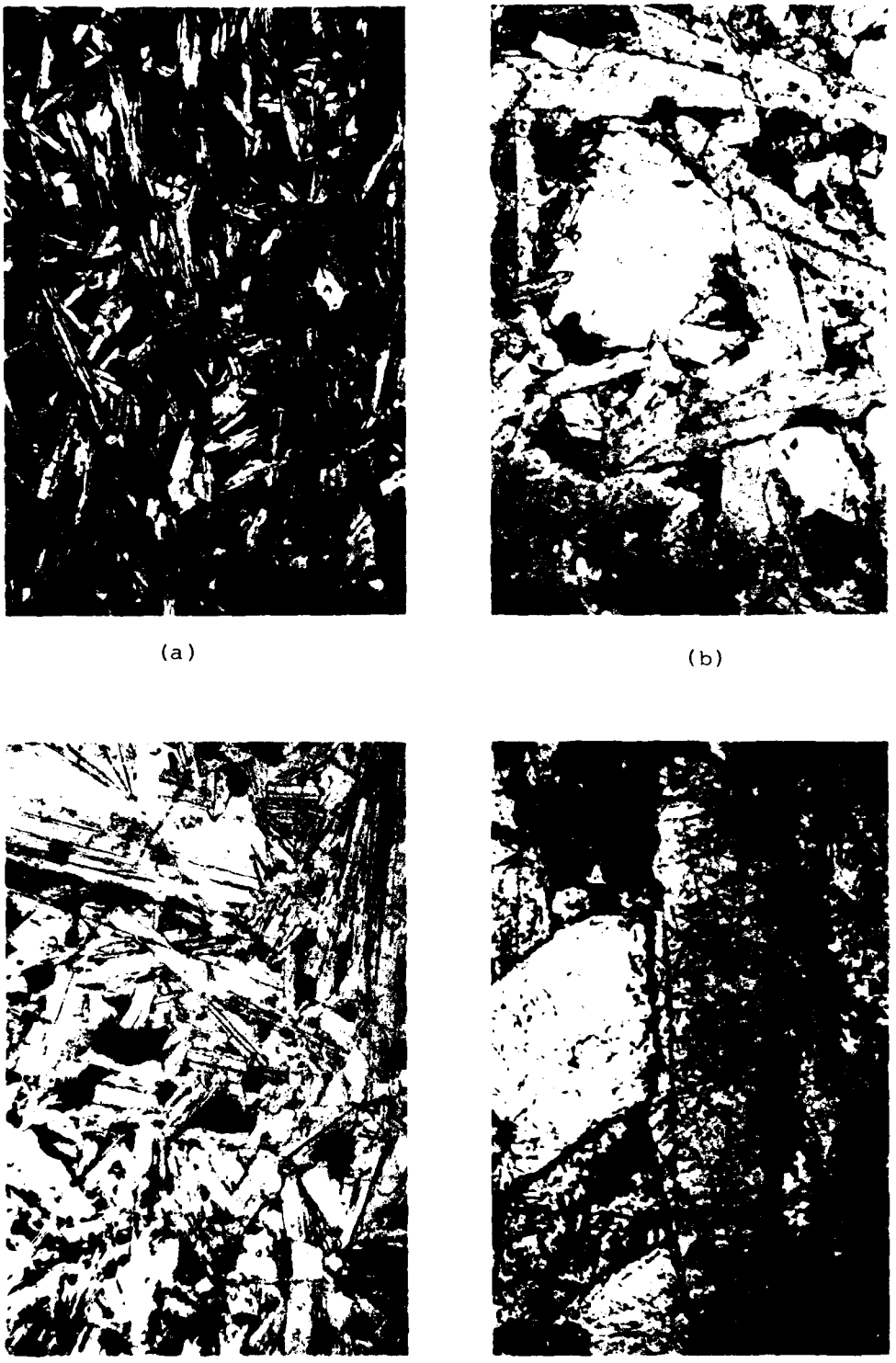
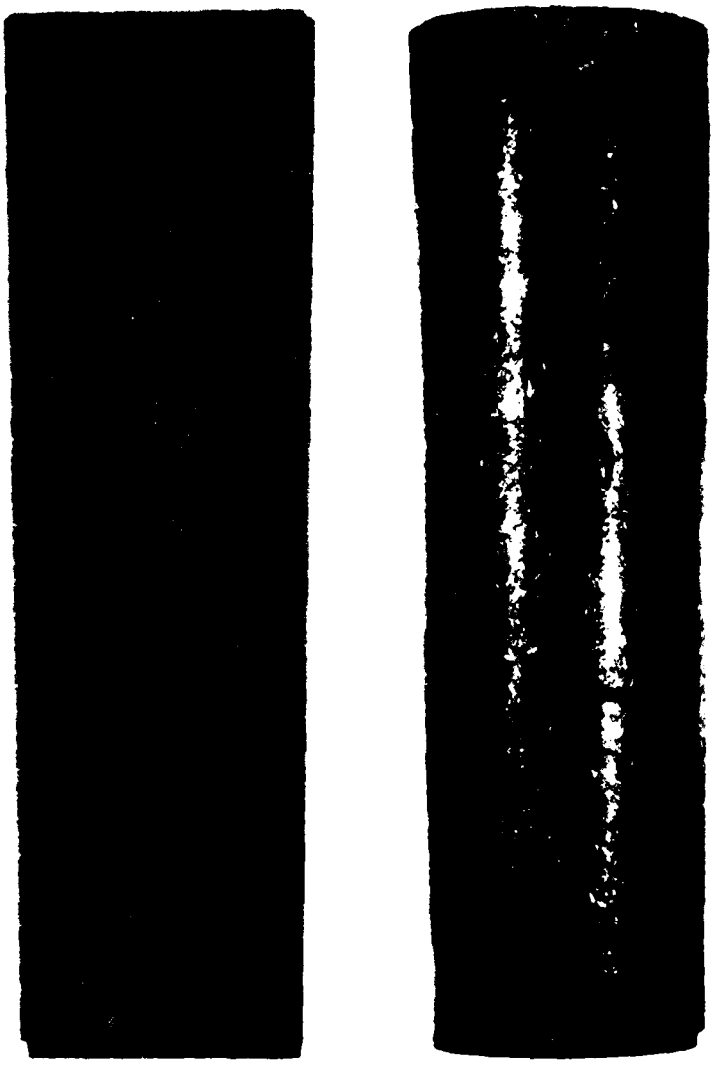


FIG. 5 - Photomicrographs of polished specimens

(a) Chilled layer of TNT-HNS cycle-cast with 0.6% HNS
(b) Bulk of TNT-HNS cycle-cast with 0.6% HNS
(c) Bulk of "poured-cloudy" TNT cast
(d) Bulk of TNT-HNS cycle-cast with 3.6% HNS showing larger grains than (b)



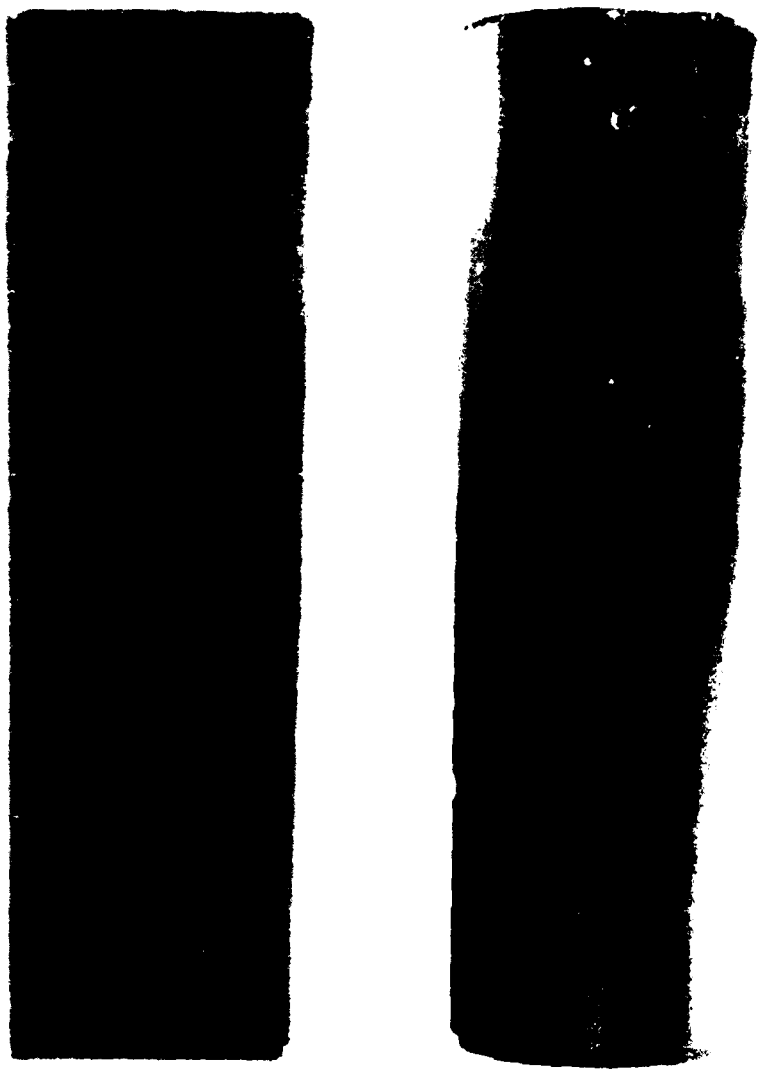
(a) (b)

FIG. 6 - "Poured-cloudy" TNT cast
(a) Fine-grained zone in bulk
(b) Chilled layer surface

(a) (b)

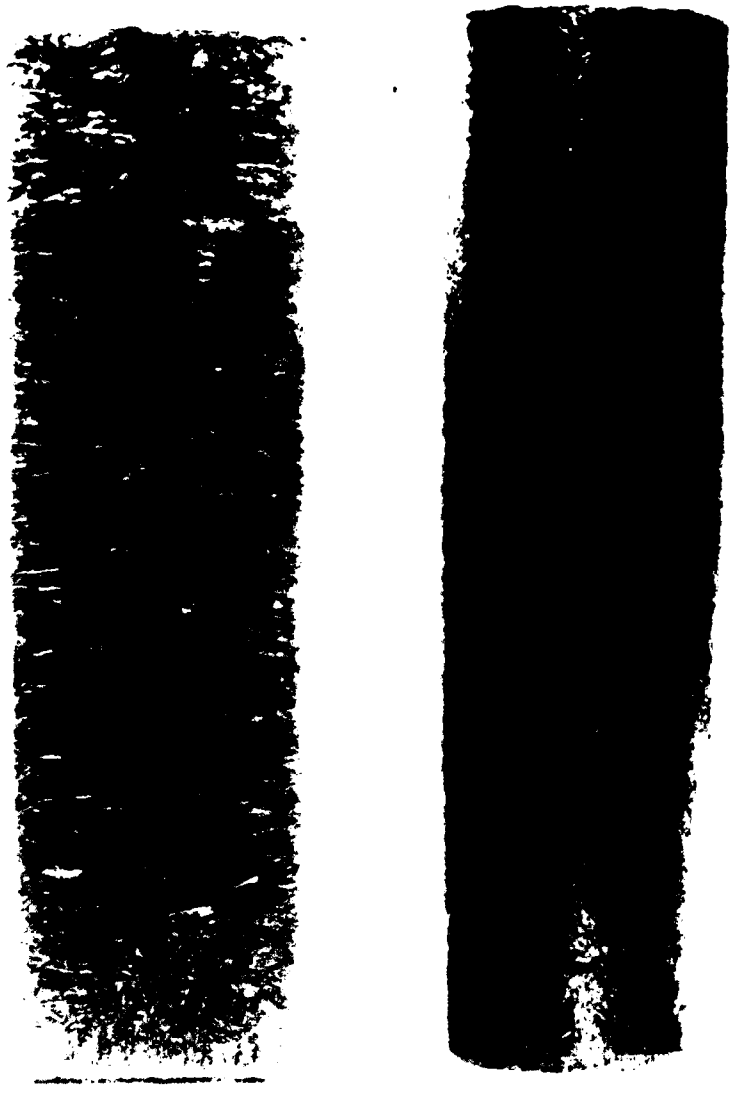
FIG. 7 - TNT-HNS cycle-cast with 4.8% HNS

(a) Bulk containing fine grains and some large grains
(b) Chilled layer surface



(a) (b)

FIG. 8 - TNT cast with addition of about 1% of $(TNT)_2HNS$ ($90^{o}C$, 4h)
(a) Fine-grained zone in bulk
(b) Chilled layer surface



(a) (b)

FIG. 9 - TNT cast with simple addition of 0.9% HNS (100°C, 1h)
(a) Bulk containing large grains and some fine grains
(b) Chilled layer surface showing large number of spherulites

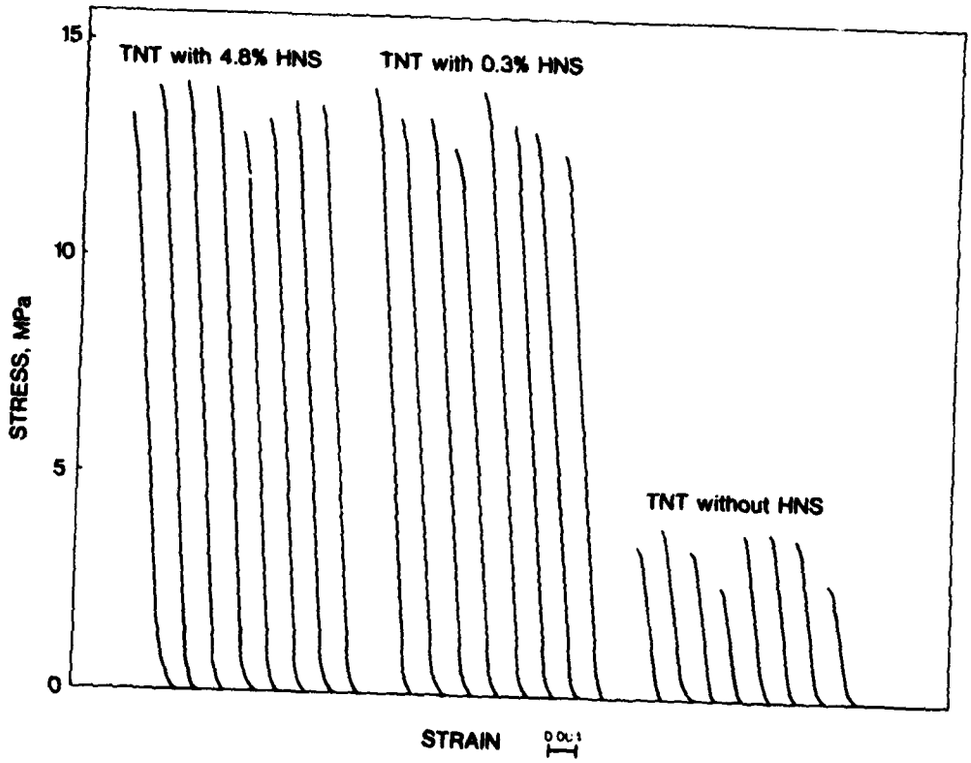


FIG. 10 - Typical stress-strain curves

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