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CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

RE-ORDER NO. 69-375

SATURATED HYDROCARBON POLYMERIC BINDER FOR ADVANCED SOLID PROPELLANT

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Chemicals and Plastics
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TECHNICAL CONTENT STATEMENT

This report contains information prepared by Union Carbide Corporation, Chemicals and Plastics Operations Division, under J.P.L. subcontract. Its content is not necessarily endorsed by the Jet Propulsion Laboratory, California Institute of Technology or the National Aeronautics and Space Administration.

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I. OBJECTIVE

Union Carbide Corporation, Chemicals and Plastics Operations Division has agreed to assist the Jet Propulsion Laboratory, California Institute of Technology, on a level of effort basis, in the development of a new or improved polymeric binder for advanced solid propellants.

The general objectives are described in Quarterly Report No. 1.

II. SUMMARY

Ethylene/propylene/3-hydroxy-3-methyl butene terpolymers have been prepared by high pressure free radical polymerization. Six samples were prepared having average hydroxyl functionalities over the range 1.2 to 2.0 and with molecular weights ranging from 1100 to 2000. A total of 26 lbs. of liquid terpolymer was prepared.

The source of an initial foaming problem during isocyanate cures of these terpolymers was found to be water or some other substance removable by a drying operation. Dried terpolymer samples cure slowly with toluene diisocyanate without the formation of bubbles at 60°C.

III. SCOPE OF PROJECT

The scope of this work remains as outlined in the work statement of our contract and as subsequently revised to include the investigation of other copolymers of ethylene.

IV. INTRODUCTION

In our previous quarterly report, we presented the results obtained when ω-bromoester telomers of ethylene and propylene were subjected to chemical reactions designed to convert the terminal functional groups, Br and -COOR, into carboxyl groups. Some measure of success was obtained, however, the conversions were not quantitative and the telomer functionality itself was not high enough to allow preparation of a curable prepolymer even if the endgroup conversions had been quantitative.

Terminally difunctional prepolymers were obtained when butadiene was added to an azo ester initiated ethylene/propylene copolymerization, however, these products contained a very high proportion of butadiene and require hydrogenation to allow preparation of a saturated prepolymer.

The advantages to be obtained from prepolymers based upon an ethylene/propylene copolymer backbone appeared great enough to justify attempts to prepare curable ethylene/propylene prepolymers by incorporation of a monomer containing reactive functionality into the copolymerization system. In the report to follow, we present the results obtained when 3-hydroxy-3-methyl-butene was terpolymerized with ethylene and propylene.

V. TECHNICAL DISCUSSION

A. Ethylene/Propylene/HMB Liquid Terpolymers as Binder Prepolymers

1. Preparation

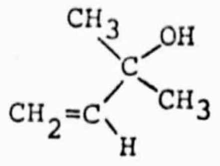
3-Hydroxy-3-methyl butene, HMB, is an interesting monomer for providing hydroxyl functionality in ethylene copolymers for several reasons:

a. It will copolymerize readily with ethylene.

b. It is not an active chain transfer agent.

c. No reactions subsequent to the polymerization step are required.

d. The tertiary hydroxyl groups introduced have a lower rate of reaction with isocyanates than the primary and secondary hydroxyl groups in other hydroxylic prepolymers currently available.



HMB

3-Hydroxy-3-Methyl Butene

With these facts in mind, we prepared a terpolymer of ethylene with propylene and HMB during a UCC sponsored program of exploratory ethylene copolymerizations. This first sample was prepared in the continuous stirred autoclave Unit II reactor at 117-122°C and 25,000 psi pressure using AIBN as the free radical initiator. A 16.3% conversion to terpolymer was obtained giving 533 grams of liquid resin having the following characteristics:

Sample Designation	28-EMS-9
Brookfield Viscosity, Poise	218
Molecular Weight	1122
Hydroxyl Equivalent Wt.	647
Hydroxyl Functionality	1.72
Penetration Temperature	-62°C

This sample was submitted to JPL where it was evaluated as a binder using toluene diisocyanate as crosslinking agent. This evaluation showed that significant advantages in propellant mix pot life and viscosity could be obtained using the 3-hydroxy-3-methyl butene terpolymer. Some foaming was noted, however, in the cures done at 190°F and 220°F (88°C and 105°C, respectively). This suggested the presence of water or other impurities interfering with the isocyanate-hydroxyl curing reaction and leading to CO_2 evolution.

Further Terpolymer Synthesis

Having established some definite advantages to be gained through the use of HMB terpolymers in solid propellant binders, we conducted a series of terpolymerizations to provide more material for evaluation as well as to provide information in the following areas:

1. Relationship between termonomer charged and hydroxyl content of resulting terpolymer.

2. The source of the foaming encountered in the initial cures at JPL.

3. Variation of cured gumstock mechanical properties with prepolymer average functionality and molecular weight.

The production data and the results of our analyses are summarized in Table I.

TABLE I

ETHYLENE/PROPYLENE/3-HYDROXY-3-METHYL BUTENE TERPOLYMERS

Run No. 28-EMS	96	100	102	104	106	113
Charge Composition						
Ethylene, wt. %	39.51	43.27	43.47	37.26	42.71	42.00
Propylene, wt. %	33.36	36.86	37.03	34.38	39.43	38.77
HMB[a], wt. %	13.18	9.54	9.37	13.76	17.35	18.68
Benzene, wt. %	13.18	9.54	9.37	13.76	0.00	0.00
Initiation Used	AIBN[b]	→	→	→	DTBP[c]	→
Initiator, wt. %	0.77	0.80	0.73	0.83	0.506	0.55
Reaction Conditions						
Temperature, °C	98-143	114-131	90-140	119-126	163-240	150-240
Pressure, mpsi	24-26	22-33	22-30	25-29	24-27	24-26
Hold-Up Time, min.	14.2	12.24	12.37	13.52	12.38	12.70
Avg Feed Rate, gms/hr	4356	4880	4806	4550	3998	3894
Total Wt. in Feed, gms	15,813	14,655	10,093	16,061	13,234	11,340
Productivity						
Yield, gms	1775	1914	1067	2035	4474	3358
Conversion, %	13.04	14.6	11.76	14.83	33.98	29.8
Production Rate, gms/hr	489	637	508	576	1352	1153
Physical & Chemical Properties						
Brookfield Viscosity, poise	290	319	388	247	467	276
Reduced Viscosity	.115	.092	.114	.111	.120	.051
Mol. Wt(VPO in ØCl @37.5°C)	1375	1706	1990	1625	1479	1528
OH Equiv. Wt.(IR Spectroscopy)	938	1575	1438	1088	764	801
OH Functionality	1.47	1.08	1.38	1.49	1.94	1.97

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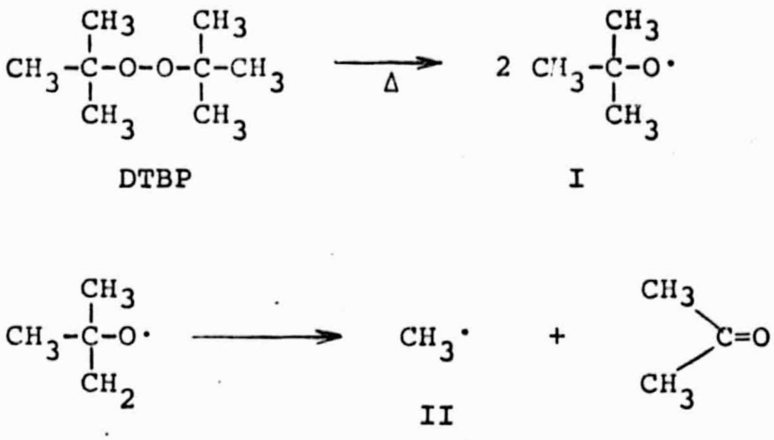
a. 3-Hydroxy-3-Methyl-Butene
b. Azobisisobutyronitrile
c. Di-*tertiary*-butyl-peroxide

Azobisisobutyronitrile (AIBN) was used as the initiator in runs 96 to 104, while di-<u>tert</u>-butyl peroxide (DTBP) was used in runs 106 and 113. The use of DTBP necessitates a higher polymerization temperature because of its greater thermal stability. The higher chain transfer activity of propylene at these temperatures is compensated for by a higher rate of polymerization which leads to higher conversions and greater overall productivity.

DTBP yields the following products upon decomposition and is expected to yield endgroups which do not interfere with subsequent curing reactions:



$$CH_3-\overset{CH_3}{\underset{CH_3}{C}}-O-O-\overset{CH_3}{\underset{CH_3}{C}}-CH_3 \xrightarrow[\Delta]{} 2\ CH_3-\overset{CH_3}{\underset{CH_3}{C}}-O\cdot$$

DTBP I

$$CH_3-\overset{CH_3}{\underset{CH_2}{C}}-O\cdot \longrightarrow CH_3\cdot + (CH_3)_2C=O$$

II

Radicals I and II are both active initiators and will lead to <u>tert</u>-butoxy and methyl end groups, respectively.

The AIBN initiated terpolymerizations yielded light amber colored oils in 11 to 15% conversion, while the two terpolymerizations initiated with DTBP yielded nearly colorless products at roughly doubled rates and conversions. Over 14 kg of terpolymer was obtained from these runs.

The molecular weights of the terpolymers were measured by vapor pressure osmometry in chlorobenzene solvent. A four point extrapolative procedure was employed as described in the appendix.

The hydroxyl equivalent weight of the terpolymers was measured by infrared spectroscopy in CCl_4 containing

25 vol. % ethylacetate following the procedure of Hudson and Muenker[1]. These measurements were combined with the V.P.O. molecular weights to give the functionalities listed in Table I . Figure 1 shows the approximately linear relationship between the amount of termonomer charged to the reactor and the hydroxyl content of the resulting terpolymers.

2. Investigation of the Foaming Problem

As our first objective in evaluating the HMB terpolymers in urethane cures it was necessary to determine the source of the foaming encountered in the cures done with the initial sample 28-EMS-9. Three possible explanations for this foaming required consideration:

a. The terpolymer was contaminated with water.

b. The terpolymer contained some COOH groups.

c. The tertiary urethane linkage is thermally unstable at the propellant processing, curing or subsequent use temperatures.

If either of the first two conditions actually were the cause of the foaming encountered, the problem could be circumvented with little or no difficulty, however, the third might place serious temperature limitations upon the utility of ethylene/propylene/HMB terpolymers as rocket propellant binders.

The following experiments were designed to determine whether any of the three possible conditions were actually the cause of the observed foaming. Terpolymer sample 28-EMS-106 as obtained from the reactor and routine solvent stripping procedure was used in these experiments.

A cure formulation was prepared from 33.358 grams (43.6 meq OH) terpolymer 28-EMS-106, 3.826 grams (43.9 meq NCO) toluene diisocyanate and .014 grams of NIAX-D22 catalyst*. The

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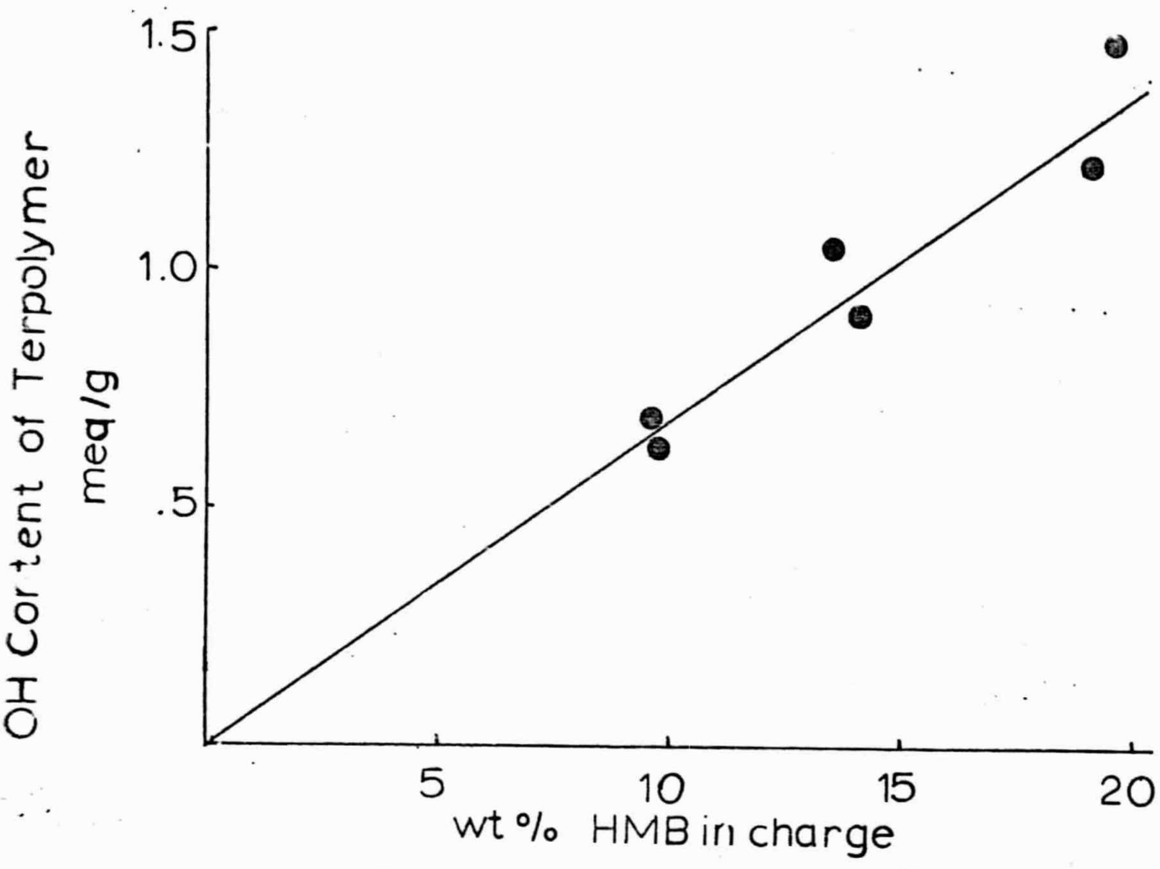
[1] See "Functionality Determination of Binder Prepolymers", Quarterly Progress Report #1, Oc. 1 - Dec. 31, 1966, by B. E. Hudson and A. H. Muenker of ESSO Research and Engineering Co. of Linden, N. J. for Air Force Contract No. F04611-67-C-0012.

* Union Carbide's brand of dibutyltindilaurate urethane catalyst.

FIGURE 1

OH CONTENT OF TERPOLYMER AS A FUNCTION OF TERMONOMER IN CHARGE



NCO to OH equivalent ratio is 1.01. Upon mixing the above components at room temperature a clear solution was initially obtained, however, very soon after addition of the catalyst, the formulation began to foam. The very fluid frothy formulation was poured into a mold composed of glass plates (14 x 9 cm, 3mm deep cavity) and allowed to cure at room temperature for eight days. At this time, the upper surface was found to be a partially cured tacky foam, and after stripping from the mold, the lower surface was found to be clear and only slightly tacky, having a Shore-A hardness of 5%. Upon storage at room temperature, the hardness gradually increased to 20% after 30 days. Because of the non-uniform foamed character of the cured formulation, no attempt to determine additional physical properties was made.

350 Grams of 28-EMS-106 was dissolved in 2500 ml heptane and treated with 100 grams of anhydrous magnesium sulfate, the solution filtered and evaporated to recover the dried terpolymer.

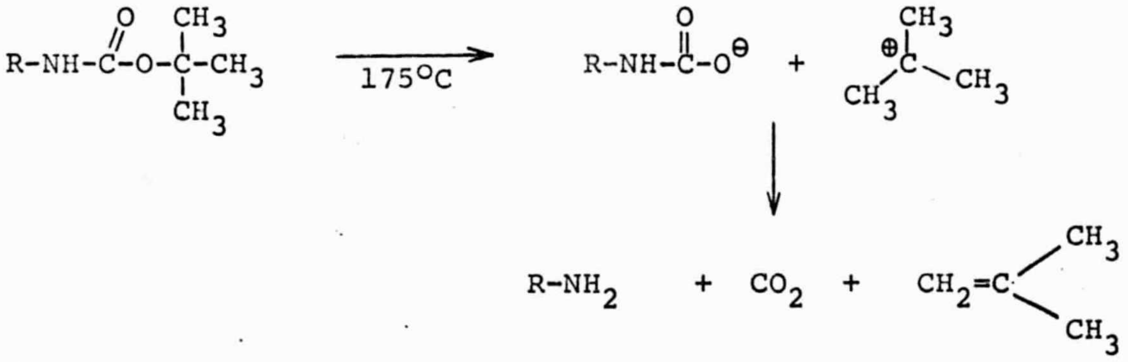
When a cure formulation employing the same proportion of ingredients used previously was tried on the "dried" 28-EMS-106, a perfectly clear mix was obtained showing no signs of foaming at room temperature This is consistent with the hypothesis that the terpolymer was "wet" as prepared and that the water + isocyanate reaction led to CO_2 evolution and the observed foaming. However, it does not prove that water itself was the actual foam generating impurity removed by the "drying" step. The clear fluid mixture was then poured into a mold and cured at 60°C for 60 hrs. at which time it was removed and found to be a clear tack-free rubber having a Shore-A hardness of 30%.

The above results suggest that condition (a) is responsible for the foaming in the aforementioned terpolymers, i.e. the terpolymers contain water which reacts with the isocyanate to give the unstable carbamic acid, which then decomposes with the liberation of CO_2. Note that terpolymer 28-EMS-106 prepared with DTBP initiator has no terminal functional groups which can provide carboxyl groups to satisfy condition (b).

With regard to possible condition (c) that the foaming was caused by decomposition of the tertiary carbamate linkages themselves, we have found that carbamates of primary, secondary and tertiary alcohols exhibit a threshold temperature above which appreciable decomposition of the carbamate linkage occurs.

This information came from a kinetic study done several years ago in these laboratories. This study showed that in the case of primary and secondary alcohol carbamates, appreciable decomposition begins to occur between 225 and 235°C. Above this temperature fission of the carbon-oxygen single bond occurs to regenerate the alcohol and the isocyanate, which itself is unstable at this temperature leading to CO_2 evolution and carbodiimide formation.

In the case of tertiary alcohol carbamates, however, appreciable decomposition begins to occur above 175°C, and by a different mechanism. In this case, fission of the oxygen-tertiary carbon bond occurs to give a tertiary carbonium ion and the anion of the carbamic acid. In all cases studied, the tertiary alcohols had β-hydrogen atoms, and subsequent degradation involved loss of the β-hydrogen from the tertiary carbonium ion to give olefin, CO_2 and an amine as the ultimate decomposition products:



We estimate from the kinetic data in the above study that the half-life for the decomposition of the t-butanol carbamate of toluene diisocyanate (TDI) is about 580 days at 80°C, too long to account for the foaming observed at JPL. At 120°C, however, the half-life is only 4.5 days and may account for some of the bubbles we observed. However, at 60°C the reaction is completely insignificant since the half-life is almost ten years.

The same kinetic studies also revealed that the tertiary alcohol carbamates of hexamethylene diisocyanate (HDI) are far more stable than those of TDI having half-lives of 90,000, 220 and 40 days at the temperatures of 80, 120 and 135°C, respectively. This greater stability as well as the lower reactivity of HDI should be very useful in propellant formulations requiring superior thermal stability. Other aliphatic diisocyanates can be devised which have the above advantage of HDI, but which have a lower volatility and present less of a toxicity hazard.

We conclude from these studies that contamination with water or some other impurity removable with drying agents is the cause of the foaming previously observed with isocyanate cures of the ethylene/propylene/HMB terpolymers. Thermal instability of tertiary carbamates will become significant at temperatures above 175°C but not under the conditions which were used for the cure studies.

3. Curing Experiments

Having established that the foaming problem encountered in the isocyanate curing of the 3-hydroxy-3-methyl butene terpolymers was either due to adventitious water or some other contaminant removed by a "drying" step, larger quantities of dried terpolymer were prepared for curing studies using the following procedure:

The terpolymer was dissolved in 6 parts of heptane and the solution stirred over granules of drierite (anhydrous $CaSO_4$) amounting to 1/3 the weight of terpolymer being dried. The dried solution was then filtered and the terpolymer recovered by evaporation of the heptane on a rotary vacuum evaporator. Terpolymer samples 28-EMS-96, 104, and 106 were subjected to this treatment. The OH equivalent weights and number average molecular weights were then redetermined for these products since both quantities are subject to change upon removal of any fraction from the original terpolymer. The revised results are listed below:

Dried terpolymer from	28-EMS-96	-104	-106
Molecular Weight	1674	1544	1510
OH Equivalent Weight	950	1018	981
OH Avg. Functionality	1.75	1.52	1.54

Using the above information, the cure formulations listed below were prepared:

Formulation	A	B
Terpolymer used, 28-EMS-	96	104
Gms Terpolymer	10.000	10.000
Meq. OH	10.53	9.82
Gms. TDI	1.063	0.983
Meq. NCO	12.22	11.29
NCO:OH ratio	1.15	1.15
Mg. NIAX D-22	11	11

The formulations were mixed under vacuum and poured into the teflon lined mold shown in Figure 2 and cured at 90°C for 19 hrs. and then at 75°C for an additional 100 hrs., cooled to room temperature and stripped from the molds, leaving the steel end-tabs attached. The formulations were found to have cured to soft rubbery solids having some bubbles near the mold edges, evidently due to trapped air from between the teflon strips. The centers of the 3/8" square bars were solid and quite clear showing no voids of any kind.

The following properties were measured on the cured samples:

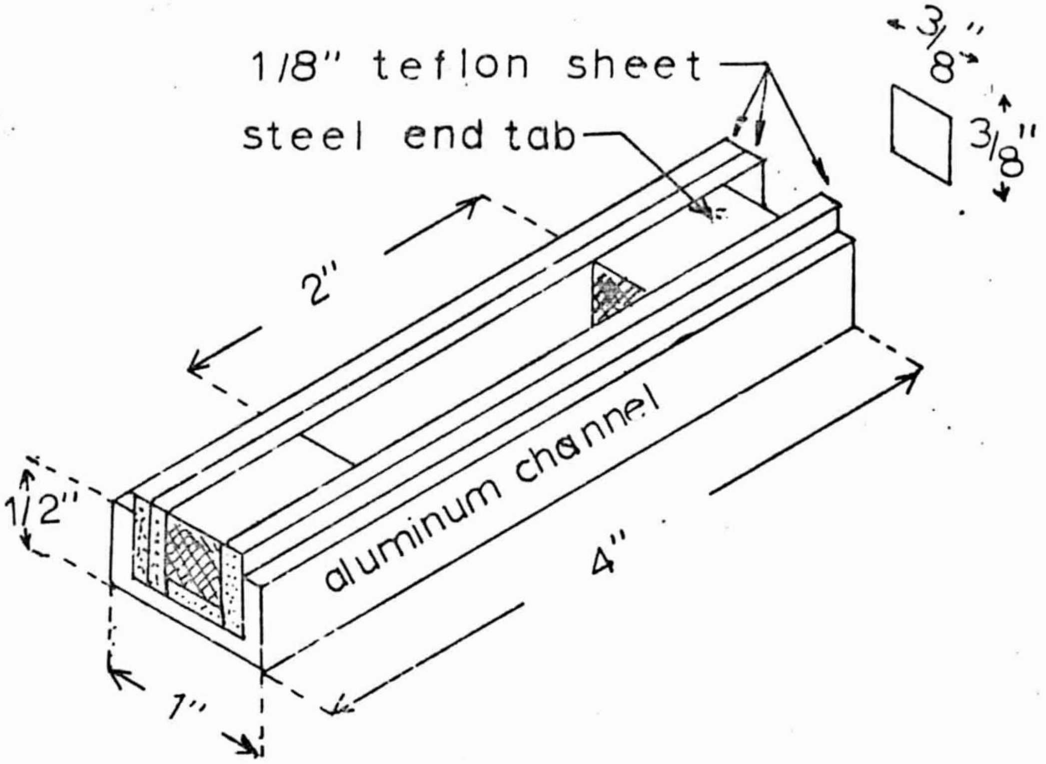
Formulation	A	B
Shore-A Hardness, %	37	30
Tensile Modulus, psi	164	109
Tensile Strength, psi	44	31
Elongation at Break, %	35	30

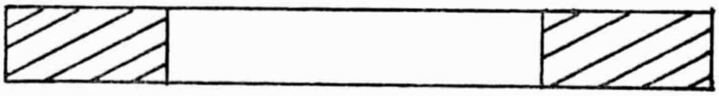
In both cases, the break was in the rubber itself rather than at the bond to the steel end-tabs. This indicates an adhesive bond strength to steel which is at least as large as the indicated tensile strength.

A sample of the dried terpolymer sample 28-EMS-106 was submitted to JPL for evaluation in propellant formulations.

FIGURE 2

TEFLON LINED MOLD AND END BONDED TEST SPECIMEN USED IN CURE STUDIES




TEST SPECIMEN, ACTUAL SIZE

VI. PLANS FOR FUTURE WORK

During the next quarter we plan to prepare other terpolymers based upon an ethylene/propylene backbone with added functionality derived from vinyl acetate.

VII. APPENDIX

A. Procedure for Determination of the Number Average Molecular Weight by Vapor Pressure Osmometry (V.P.O.)*

The technique of vapor pressure osmometry is based upon the fact that a solution exhibits a lower vapor pressure at a given temperature than the pure solvent. Because of this fact, solvent vapor will condense onto a droplet of a solution placed into a chamber saturated with solvent vapor, until the heat of vaporization liberated by the condensing solvent vapor raises the temperature of the droplet of solution to the point that the solution's vapor pressure just balances the vapor pressure of the pure solvent. The temperature difference which develops between a solution droplet and a solvent droplet adjacent to one another in a chamber saturated wtih solvent vapor is thus a colligative property of the solution related directly to its molar concentration.

This temperature difference is normally quite small, but can be measured with sufficient precision by placing the droplets of solution and solvent upon the beads of matched thermistors which are connected to a bridge circuit designed

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* For this work we used a model 302 Hewlett Packard Vapor Pressure Osmometer.

between the two thermistors. The relationship between ΔR and the molar concentration is given by:[2]

$$1. \quad \Delta R = a_1 C_m + a_2 C_m^2$$

or alternatively:

$$2. \quad \frac{\Delta R}{C_m} = a_1 + a_2 C_m$$

The parameter a_1 is independent of the solute and depends only upon the thermodynamic properties of the solvent and the thermistor characteristics. The parameter however varies with the solute properties and the interactions between the solvent and solute as well. Thus, given a particular solvent and instrument, the parameter a_1 is a constant and can be determined by measurement of ΔR as a function of the concentration of a pure chemical substance of known molecular weight.

A very convenient procedure generally used for determining a_1 from these data is to prepare a plot of $\Delta R/C_m$ versus C_m. Extrapolation of the linear plot usually obtained to $C_m = 0$ gives a_1 directly as the value of the intercept on the $\Delta R/C_m$ axis. The slope of the linear plot gives a_2.

For an unknown solute of molecular weight M, the following relationship holds between ΔR, M, and the concentration of the solute expressed in terms of grams/liter:

$$1') \quad \Delta R = a_1 \frac{C_g}{M} + a_2 \frac{C_g^2}{M^2}$$

and

$$2') \quad \frac{\Delta R}{C_g} = \frac{a_1}{M} + \frac{a_2}{M^2} C_g$$

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[2] F. W. Billmeyer, Jr., and V. Kokle, J. Am. Chem. Soc., 86, 3544 (1969).

A plot of $\Delta R/C_g$ versus C_g extrapolated to $C_g = 0$ gives a_1/M as the intercept and a_2/M^2 as the slope. Having previously determined a_1, M is given by:

$$M = \frac{a_1}{\left(\frac{\Delta R}{C_g}\right)_{C_g \to 0}} .$$

Unfortunately, this simple and traditional V.P.O. procedure has a major shortcoming: fitting of a linear equation to plots of $\Delta R/C$ vs. C in order to determine the parameters a_1 and a_2 in the original equations 1 and 1' is justifiable only when the errors inherent in the measurement of ΔR and C have a correlation factor of 1.0 between them[3]. This is not the case. C being determined by weight and dilution, is rather precisely known, while ΔR is subject to random fluctuations which become a serious fraction of the measured value at low concentrations. This leads to excessive scatter of data points at low concentrations, and frequently a net upward curvature of the plot as $C \to 0$. This makes accurate manual extrapolation to $C = 0$ difficult, and least squares fitting of the data to a linear equation statistically unsound since too much weight is given to the less precisely known values of ΔR obtained at low values of C.

To avoid this problem, it is preferrable to fit the data directly to the quadratic equations 1 and 1' rather than use the simpler linear equations. This cannot be accomplished by a convenient graphical procedure, however. To facilitate handling all the data resulting from routine V.P.O. measurements, a short Fortram program was written for the IBM 1130. This program uses a least squares subrontine fitting the data to a quadratic equation passing through the origin to give instrument calibration constants from ΔR vs. C_m measurements on known standards and $\overline{M}_n$ and a_2 parameter values from measurements of ΔR vs. C_g on unknowns.

We have calibrated our instrument in chlorobenzene solvent at 37°C using cholesterol and sucrose octaacetate as primary standards. The resulting a_1 value was found to be 146.7 ohms x liters/mole.

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[3] A. Adicoff and W. J. Murbach, Anal. Chem., 39, 302 (1967).

Unknown polymer samples are accurately weighed and dissolved in the same chlorobenzene solvent used to saturate the V.P.O. vapor space. Four different concentrations are generally used: 100, 75, 50, and 25 g/l. The data points are usually plotted as $\Delta R/C_g$ vs. C_g as they are obtained. This permits a quick check upon the consistency of the data and allows an early estimate of the molecular weight if a good linear fit is obtained. Subsequently, the data from a series of molecular weight determinations are transferred to punched cards and read into the computer along with standardization data. After the data has been processed, a printout of the final results is obtained.

The Fortran program "VPO2" used for the data reduction is given in Figure 3 and a sample of the printout resulting from it is given in Figure 4.

pgf

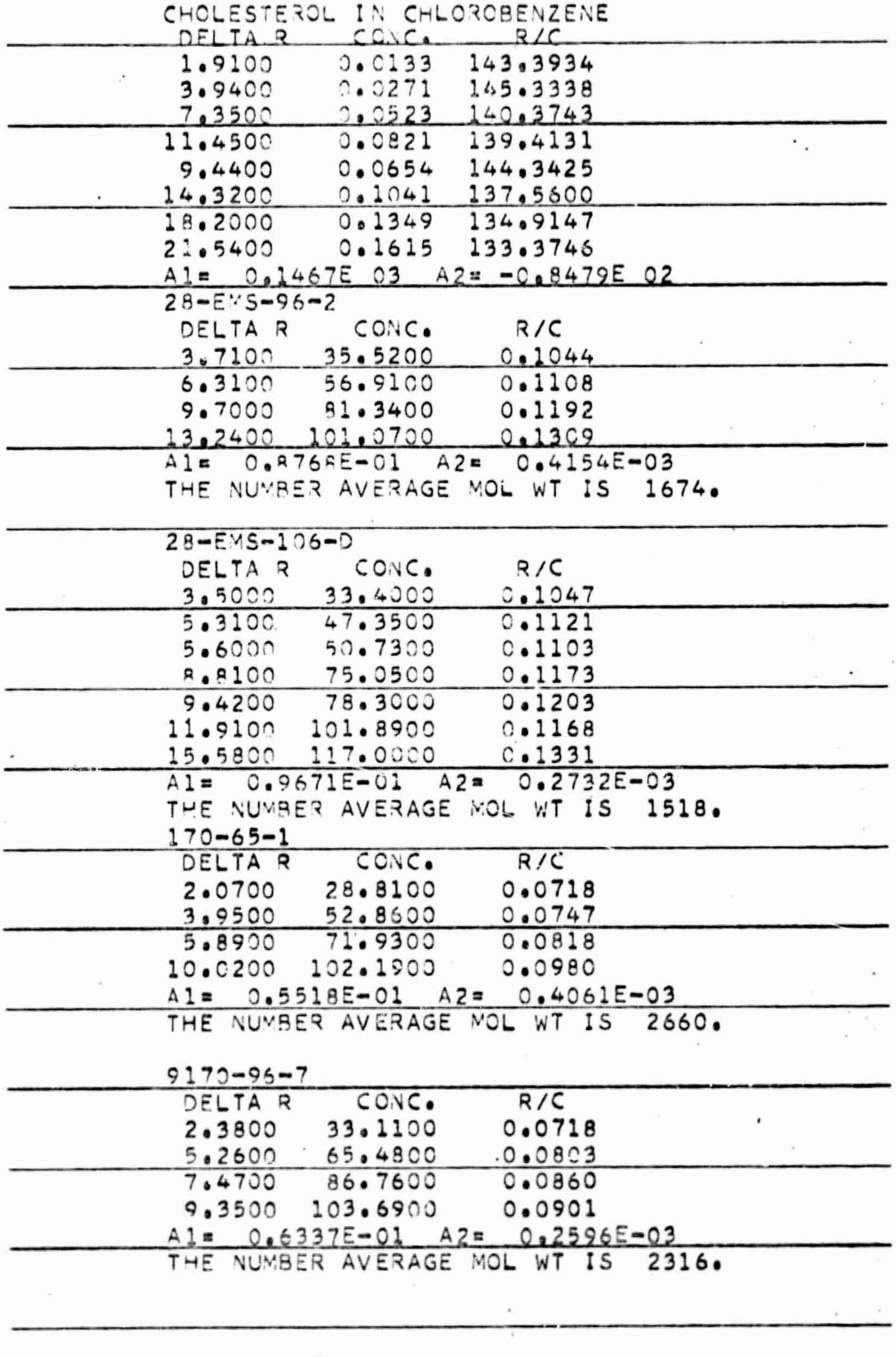
FIGURE 3

FORTRAN PROGRAM VPO2 FOR VPO DATA REDUCTION

```
C     VAPOR PHASE OSMOMETRY DATA REDUCTION
C
      REAL K,KCAL,MN
      DIMENSION RC(25)
      COMMON C(25),R(25)
    4 READ(2,10)J
      L=J-3
      IF(L)6,5,6
    6 READ(2,12)
      WRITE(3,12)
      WRITE(3,16)
   16 FORMAT(1H ,' DELTA R     CONC.      R/C')
   12 FORMAT(50H                                                  )
      READ(2,10)II
   10 FORMAT(I2)
      DO 3 I=1,II
      READ(2,11)R(I),C(I)
   11 FORMAT(2F10.5)
      RC(I)=R(I)/C(I)
    3 WRITE(3,17)R(I),C(I),RC(I)
   17 FORMAT(F8.4,2X,F8.4,2X,F8.4)
      CALL MLSQQ(II,K,S)
      WRITE(3,14)K,S
   14 FORMAT(1H ,'A1=',E12.4,'  A2=',E12.4)
      GO TO(1,2,3),J
    1 KCAL=K
      GO TO 4
    2 MN=KCAL/K+.5
      WRITE(3,15)MN
   15 FORMAT(30H THE NUMBER AVERAGE MOL WT IS ,F6.0)
      GO TO 4
    5 CALL EXIT
      END
      SUBROUTINE MLSQQ(N,A1,A2)
C      LEAST SQUARES FIT OF BIVARIATE DATA, QUADRATIC THRU ORIGIN
      COMMON X(25),Y(25)
      SY=0.
      SXY=0.
      SX=0.
      SXQ=0.
      SXK=0.
      DO 1 I=1,N
      SY=SY+Y(I)
      SXY=SXY+X(I)*Y(I)
      SX=SX+X(I)
      SXK=SXK+X(I)**3
    1 SXQ=SXQ+X(I)**2
      T1=SY*SXK-SXQ*SXY
      T2=SX*SXY-SY*SXQ
      B=SX*SXK-SXQ**2
      A1=T1/B
      A2=T2/B
      RETURN
      END
```

FIGURE 4

SAMPLE OF PRINTOUT FROM VPO2



```
CHOLESTEROL IN CHLOROBENZENE
 DELTA R      CONC.       R/C
 1.9100     0.0133   143.3934
 3.9400     0.0271   145.3338
 7.3500     0.0523   140.3743
11.4500     0.0821   139.4131
 9.4400     0.0654   144.3425
14.3200     0.1041   137.5600
18.2000     0.1349   134.9147
21.5400     0.1615   133.3746
A1=  0.1467E 03   A2= -0.8479E 02
28-EMS-96-2
 DELTA R      CONC.       R/C
 3.7100    35.5200     0.1044
 6.3100    56.9100     0.1108
 9.7000    81.3400     0.1192
13.2400   101.0700     0.1309
A1=  0.8768E-01   A2=  0.4154E-03
THE NUMBER AVERAGE MOL WT IS  1674.

28-EMS-106-D
 DELTA R      CONC.       R/C
 3.5000    33.4000     0.1047
 5.3100    47.3500     0.1121
 5.6000    50.7300     0.1103
 8.8100    75.0500     0.1173
 9.4200    78.3000     0.1203
11.9100   101.8900     0.1168
15.5800   117.0000     0.1331
A1=  0.9671E-01   A2=  0.2732E-03
THE NUMBER AVERAGE MOL WT IS  1518.
170-65-1
 DELTA R      CONC.       R/C
 2.0700    28.8100     0.0718
 3.9500    52.8600     0.0747
 5.8900    71.9300     0.0818
10.0200   102.1900     0.0980
A1=  0.5518E-01   A2=  0.4061E-03
THE NUMBER AVERAGE MOL WT IS  2660.

9170-96-7
 DELTA R      CONC.       R/C
 2.3800    33.1100     0.0718
 5.2600    65.4800     0.0803
 7.4700    86.7600     0.0860
 9.3500   103.6900     0.0901
A1=  0.6337E-01   A2=  0.2596E-03
THE NUMBER AVERAGE MOL WT IS  2316.
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