

Creep performance of mounting tapes using hot melt pressure sensitive adhesives

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DUE TO ADVANCES IN ADHESIVE and coating technology and in the production of affordable carrier materials, new uses have become available for double-faced pressure sensitive tapes in semistructural applications. Creep resistance is an essential property of the pressure sensitive adhesive in these applications. Unlike transfer tapes that consist of an unsupported adhesive film, mounting tapes usually have a carrier with a coating of the same or different pressure sensitive adhesives on both sides.

Using primers, corona treatment, or fluorination on the carrier can improve the adhesion between the carrier and the adhesive. Automotive applications for these tapes include bonding of fender moldings, mirror lenses, emblems, door sills, spoilers, and dampening sheets. In all these applications, the tape holds the assembly together, absorbs temperature shocks, compensates for surface irregularities, and reduces vibrations because of its viscoelastic properties (1).

Many publications have shown the relation between the key properties of pressure sensitive adhesives such as peel resistance and tack and the viscoelastic characteristics measured by dynamic mechanical analysis (DMA) (2, 3). The events responsible for the creep of pressure sensitive adhesives occur at a much lower frequency range. A difference also exists between creep failure and creep damage of a joint. Creep failure is a complete or partial separation of a bonded structure. Creep damage can occur when the de-

formations due to creep affect the use of the bonded object. Combining data collected in creep experiments with the standard test methods for pressure sensitive adhesives provides a complete characterization and evaluation of such an adhesive system.

EXPERIMENTAL

All tests used aluminum foil and sheeting as substrate materials because semistructural applications usually include metal joints. Pressure sensitive mounting tapes are of special interest for lightweight constructions. Since the temperature resistance of foamed polyolefin carriers is approximately 130°C, the range of suitable hot melt pressure sensitive adhesive has a limitation imposed by their melt viscosity. This property must be sufficiently low at this temperature to allow reasonable coating speeds.

The standard styrene-isoprene-styrene (SIS) rubber system used as a reference in this study could not be applied by the hot melt process to the polyolefin carrier. It required coating from a toluene solution. The new generation of ultraviolet curable, acrylic based hot melt pressure sensitive adhesives meets the demand concerning melt viscosity because crosslinking occurs after the coating process. As with all radiation curable polymers, the cross-linking density depends on depth due to ultraviolet adsorption on its way through the adhesive (4).

The coating thickness of the adhesive requires precise control to ensure repeatable results and to reduce scattering. The results in this study used a

ABSTRACT

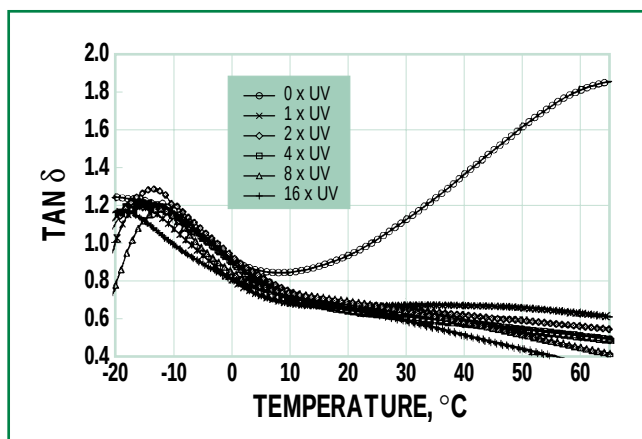
Pressure sensitive mounting tapes are environmentally friendly alternatives to liquid adhesives. Foamed polyolefin as a carrier material offers excellent performance at an attractive price and good recycling characteristics. This study evaluated hot melt pressure sensitive adhesives using ultraviolet curable acrylic resins coated on foamed polyolefin. DMA measurements, peel test, and loop tack test evaluated the basic pressure sensitive adhesive properties. Creep tests with single lap shear specimens gave information about the shear adhesion failure temperature and quantitative creep data. Evaluation of the acrylic system used a standard rubber based hot melt pressure sensitive adhesive for comparison.

Application:

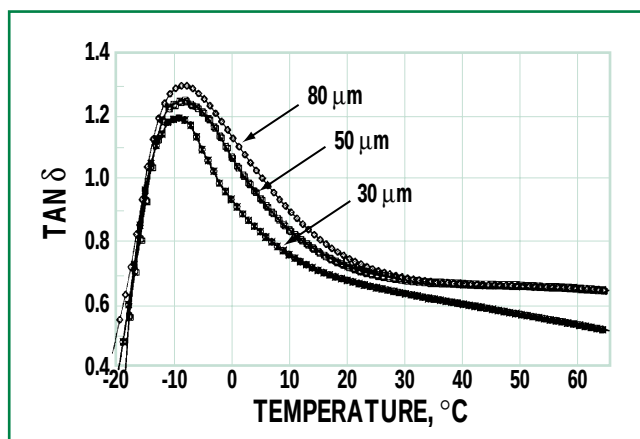
A mounting tape using an ultraviolet cured acrylic hot melt pressure sensitive adhesive on a polyolefin film provides satisfactory performance in semistructural applications.

commercially available acrylic adhesive supplied ready for use with a copolymerized and therefore non-volatile photoinitiator. A microwave oven can easily soften small portions of this adhesive. The SIS hot melt pressure sensitive adhesive used for reference contained 100 parts commercial SIS polymer and 110 parts commercial tackifier resin and 2 parts commercial stabilizer. Preparation of this adhesive used a 5-kg hot melt mixer under nitrogen atmosphere of 500 kPa with degassing under vacuum before application.

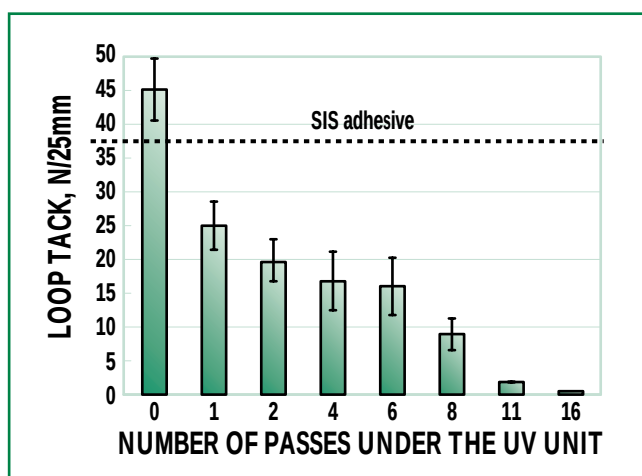
Coating used a small, heatable table-like laboratory coater that can coat sheets of 0.3 m x 0.5 m with an accuracy of 5 µm. Coating thicknesses with the ultraviolet curable acrylic adhesive were 30 µm, 50 µm, and 80 µm. The SIS hot melt adhesive thickness was 50 µm. The ultraviolet curing of all samples used a commercially avail-



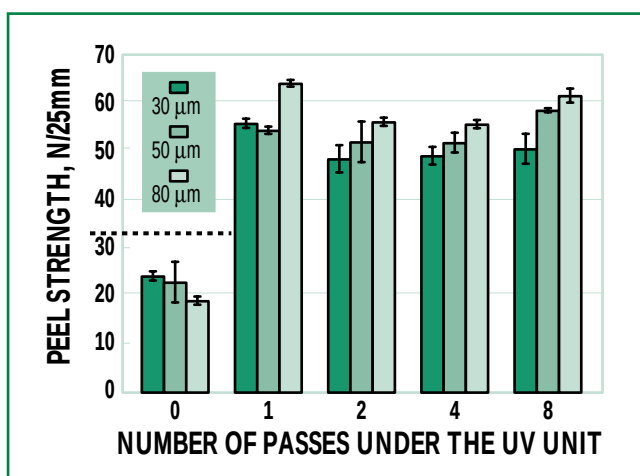
1. DMA temperature scan at 1 Hz of acrylic adhesive at 50 μm for 16 passes through the ultraviolet unit



2. DMA temperature scan at 5 Hz for films of 30 μm , 50 μm , and 80 μm acrylic adhesive after five passes through the ultraviolet unit



3. Loop tack for acrylic adhesive showing SIS adhesive as reference at 22°C



4. Peel strength at 10 mm/min for acrylic adhesive at 20°C

able single ultraviolet unit equipped with a 160 W/cm lamp and reflector at a working distance of 100 mm and a line speed of 600 mm/min. The reflector allows the infrared radiation of the ultraviolet source to pass through and be conducted to the cooling system. Only the ultraviolet portion of the emitted radiation focuses on the substrate. The number of passes through the ultraviolet unit determined the total ultraviolet dose.

DMA used a commercial unit in double shear mode. The acrylic adhesive was coated directly on a sheet of release foil, and the adhesive films were stacked after ultraviolet crosslinking in a sandwich of 20–30 layers to form a sheet of pure adhesive that was easier to handle and measure

than a single film with a thickness of just 30–80 μm .

For the 180° peel test, the adhesives were coated directly onto a 0.15-mm aluminum foil. The sheets were cut into 25 mm wide strips and rolled onto 1.5 mm steel specimens measuring 100 mm x 25 mm with a 4.5 kg rubber-covered roller according to Pressure Sensitive Tape Council (PSTC) test 1. After a dwell time of 50 h, the samples were tested at 10 mm/min and 100 mm/min. Two speeds were chosen because the difference in peel force in the fast and the slow peel tests depends on the crosslinking density and can help characterize the adhesive.

The loop tack test used uncoated strips of 0.15 mm aluminum foil on

sheets of 1.5 mm steel coated with 30 μm , 50 μm and 80 μm of acrylic adhesive or with 50 μm of SIS adhesive. The advantage of this procedure is that the aluminum strips are easier to cut and handle when not coated with adhesive.

This study used a commercially available foamed polyolefin carrier with a volume of 15 m³/kg and a thickness of 1.0 mm. The carrier was first coated with the ultraviolet crosslinkable hot melt pressure sensitive adhesive on both sides and then run through the ultraviolet unit. Between passes, the opposite side was covered with a sheet of release foil. The reference SIS adhesive could not be coated as a hot melt and had to be dissolved in toluene for the coating process.

The prepared sheets of mounting tape were cut into pieces 25 mm x 25 mm, placed on the surface of the lap shear specimens, and rolled twice with a 2-kg roller according to PSTC test 7. After removing the release liner, the second metal strip was placed on the sample and again rolled twice. These specimens were then tested in the creep experiment after a dwell time of 50 h.

The various methods for testing the shear resistance of pressure sensitive tapes are very similar. The Association of European Self-Adhesive Tape Manufacturers (AFERA) 4012 defines shear adhesion as the load that leads to slippage of a sample of 2.5 mm (bonding area = 25 mm x 25 mm), and PSTC test 7 specifies reporting slippage to the nearest 1/64 of an inch or the time taken for the tape to separate from the panel. In practice, results are often presented as the elapsed time in hours or minutes until the failure of the sample occurs. **Table I** gives an overview of the standardized test procedures.

The test of shear adhesion failure temperature (SAFT) provides a good characterization of the temperature limits of pressure sensitive adhesives. In the SAFT test, the samples are prepared similarly to the shear tests and placed in the testing device. Temperature is increased at a given rate until the sample fails. A typical heating rate is 0.4°C/min, and a typical load is 1 kg/625 mm².

All creep results in this study used single lap shear samples and a bonding area of 25 mm x 25 mm. The substrate material was plastic. The combined creep and SAFT experiments used a heating rate of 2°C/h and an offset time of 5 h.

RESULTS AND DISCUSSION

Dynamic mechanical analysis

Other publications have discussed the dynamic mechanical behavior of the SIS reference adhesive (5, 6). The viscoelastic properties of the ultraviolet

crosslinkable acrylic adhesive depend on the amount of ultraviolet radiation. The effects of crosslinking are evident in the high temperature region of the DMA curve while the glass transition temperature remains unchanged. In the uncrosslinked state, the viscous properties dominate

the behavior. With increasing temperatures, the storage modulus, G' , decreases to values below G'' . Because of this, $\tan \delta$ has values greater than 1. With increased ultraviolet radiation and increased crosslinking, G' in the high temperature region increases and $\tan \delta$ in this area decreases to 1 or less. The practical effect of the photoinitiated crosslinking reaction is that the adhesive can no longer be molten or dissolved. The crosslinked adhesive is then in a gel state. **Figures 1 and 2** plot the $\tan \delta$ values at a test frequency of 1 Hz vs. the temperature. Choosing $\tan \delta$ instead of G' eliminates the experimental errors caused by variation of the total thickness of the sample and small inclusions of air that can occur during the laminating of the adhesive sandwich.

Since the ultraviolet radiation is absorbed and dispersed on its way through the adhesive and to some degree reflected at the surface of the sub-

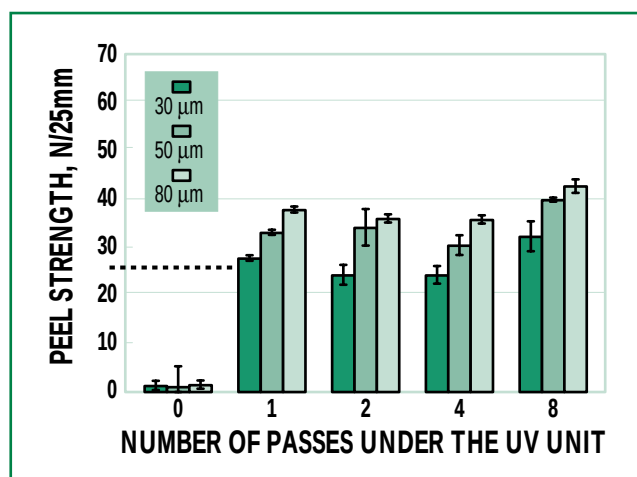
strate, the average crosslinking density depends on the thickness of the adhesive layer. The results of the 30 μm , 50 μm , and 80 μm films therefore vary slightly.

Loop tack

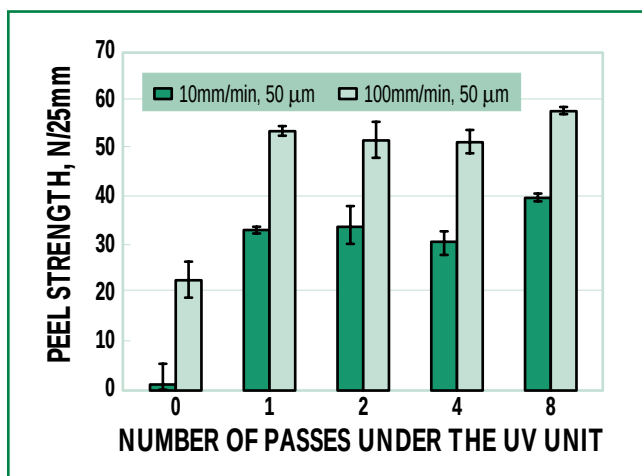
Since the loop tack samples in this study did not exactly conform to the standard testing procedures, a common reference adhesive formulation was included to make the results comparable. The acrylic and SIS adhesives were coated in a thickness of 50 μm on sheets of plated steel and tested with an uncoated test loop of 0.15 mm aluminum foil. The results of the ultraviolet crosslinkable acrylic adhesive show that even the first pass under the ultraviolet lamp causes a significant reduction of tack. After sixteen radiation cycles, the tack properties fail completely, and a peculiar smell of the adhesive shows the onset of degradation in the over-irradiated top layers of the coating.

Test	Load	Size	Substrate	Temperature
FINAT No. 8 (FTM 8)	1 kg	25 mm x 25 mm	Float-glass	23°C (p = 50%)
ASTM 3654 PSTC 7	Typically 1 kg	0.5 in. x 0.5 in. or 1 in. x 1 in.	Steel	23°C
AFERA 4012	0.5 kg – 8 kg	25 mm x 25 mm	Stainless steel	23°C and 70°C

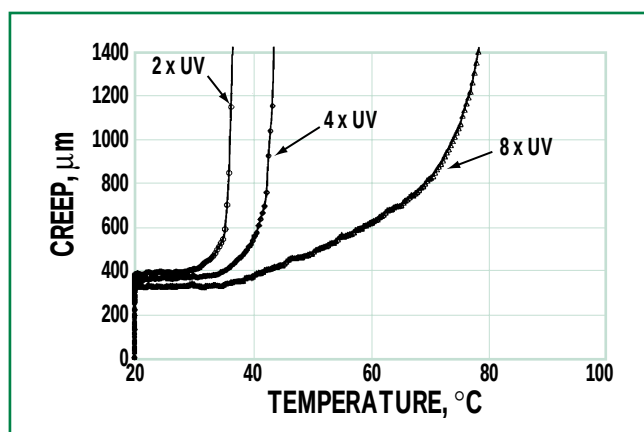
I. Characteristics of standardized shear tests



5. Peel strength at 100 mm/min for acrylic adhesive at 20°C



6. Peel strength at varying peel velocities for 50 µm acrylic adhesive at 20°C

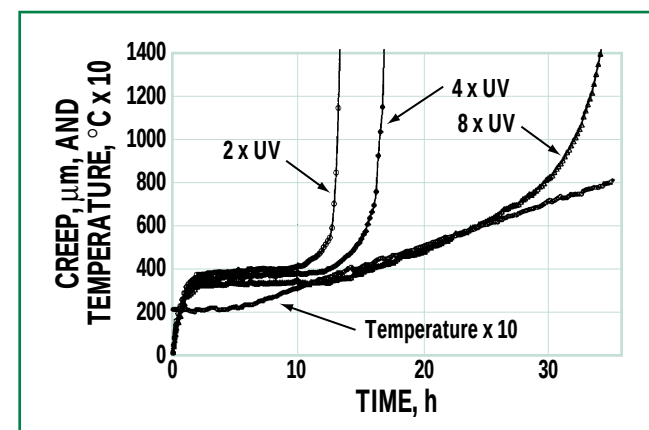


8. Creep as a function of temperature for 80 µm acrylic adhesive on 1.0 mm foamed polyolefin

Figure 3 shows the relation between ultraviolet dose and tack. The dotted horizontal line indicates the average tack of the SIS formulation with the admixture of 5 parts of a commercial oil.

180° peel test

All peel tests used aluminum samples. The adhesives were coated on aluminum foil and then rolled onto steel sheets. The peel properties of the ultraviolet crosslinkable adhesive fol-



7. Creep and temperature ramp for 80 µm acrylic adhesive on 1.0 mm foamed polyolefin

lowed the expected pattern. The uncrosslinked samples separate cohesively in the adhesive layer. Viscous separation during the peel test is a result of adhesive flow and therefore depends very much on the speed of peeling. A greater thickness of the adhesive also reduces the peel strength in

this state. One pass through the ultraviolet unit leads to an adhesive with gel properties in the upper layers of the coating and poorly crosslinked adhesive near the substrate surface. The incompletely crosslinked adhesive coating separates in a mixed mode during peel with areas of cohesive and adhesive failure. These samples usually have the highest peel strength. Further crosslinking reduces the peel strength and finally leads to a purely adhesive separation of the specimens. In this failure mode, higher peel rates and greater coating thickness lead to higher peel strength if the peel velocity has not entered the stick-slip region.

The tests used three different coating thicknesses. Figures 4 and 5 show the results of the 10 mm/min and 100 mm/min experiments. The

two horizontal lines show the average peel values of the SIS reference adhesive with no admixture of oil. Both adhesives were applied in a hot melt coating process.

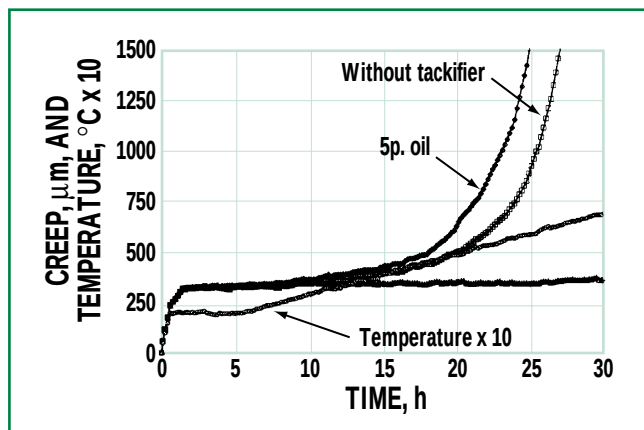
Figure 6 illustrates the influence of the peel rate. The ratio of peel strength for the samples with slow and fast peel rate decreases with the number of irradiation cycles as the crosslinking density reaches its maximum.

Creep

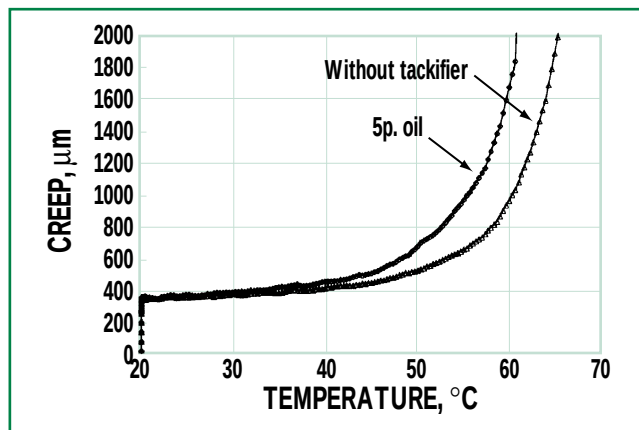
Creep and temperature performance can be characterized by thermal creep measurements with single lap shear specimens providing not only the SAFT but also quantitative creep data (7). The ultraviolet crosslinkable acrylic adhesive and the SIS reference adhesive were coated on both sides of the 1 mm thick carrier consisting of foamed polyolefin. The acrylic adhesive was again varied in crosslinking density by the number of passes through the ultraviolet unit. The SIS reference adhesive was tested with and without an admixture of 5 parts of tackifier oil. Testing was done with single lap shear specimens of plastic using a bonding area of 25 mm x 25 mm, a constant load of 10 N, and a heating rate of 2 K/h beginning at 20°C. An offset time of 5 h occurred before beginning the temperature ramp allowing the samples to reach an undisturbed state of creep. The temperature of each sample was con-

KEYWORDS

Adhesive tape, creep, foam plastic, hot melts, mechanical tests, mounting, physical properties, polyacrylics, polyhyrocarbons, polyolefins, pressure sensitive adhesives, sealants, test methods.



9. Creep and temperature ramp for 80 µm SIS adhesive on 1.0 mm foamed polyolefin



10. Creep as a function of temperature for 80 µm SIS adhesive on 1.0 mm foamed polyolefin

trolled and regulated independently by an electrical heating unit. The temperature and creep data were collected every 5 min.

Figures 7 and 8 show the creep behavior of the differently crosslinked acrylic samples. In addition, the temperature data from one sample is included in the diagram. In the first 10 h, all three samples behave similarly. The modest load does not cause a great difference in creep velocity. When the temperature reaches 30°C, the creep velocity of all samples accelerates, and the double irradiated sample fails at 37°C. The sample with four passes under the ultraviolet lamp next fails at 44°C. Eight irradiation cycles improve the temperature resistance of the adhesive drastically. Although the creep velocity clearly increases, this sample reaches 78°C before failure occurs.

The SIS system in Figures 9 and 10 exhibits similar creep behavior. The formulation with 5 parts of tackifier oil fails at 61°C, and the basic formulation lasts to 67°C under these conditions. Other authors have investigated the SAFT of the SIS reference adhesive and reported a value of 99°C for a formulation of 100 parts polymer and 110 parts resin with no tackifier oil on steel substrates. The explanation for the apparent difference is due to the different heating rates. In this study, the heating rate was 2 K/h to obtain enough information about the quantitative creep behavior. Other variations of the unstandardized SAFT test use heating ramps up to 30 K/h. Faster

heating naturally shifts the failure temperature to higher values. Use of a carrier in this study also has an influence on the state of stress in the adhesive layer that can affect the failure mode of the adhesive.

SUMMARY AND RECOMMENDATIONS

The results show that the investigated construction of a mounting tape based on a polyolefin carrier and an ultraviolet crosslinkable acrylic adhesive are satisfactory for semistructural applications. Wetting of the polyolefin surface did not cause any problems during the coating process. Additional long time creep experiments at room temperature did not show a blind side between adhesive and carrier material. An ultraviolet dose leading to an optimum combination of tack and creep properties did not occur when using the simple direct coating process. With transfer coating, the adhesive film is irradiated on a silicone coated backing paper and then transferred to its final carrier. This process involves the use of additional release materials. Another alternative is not to irradiate the adhesive evenly but to generate a radiation pattern by using a mask or a scanning ultraviolet laser. This can generate a microstructure of various degrees of crosslinking on the adhesive film and help to combine excellent tack and creep properties in a single adhesive layer of ultraviolet crosslinkable pressure sensitive adhesive. Our first experiences with this technique were

promising, but further research is necessary. TJ

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